Doctoral Thesis

Development of Social and Environmental Footprint Database Using Input-Output Analysis for Life Cycle Sustainability Assessment in Thailand

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Abstract

Background and objectives: With the growing concern about environmental and social issues, the environmental input-output analysis (EIOA) and social input-output analysis (SIOA) have become important tools for policy decision making and footprint assessments in trade. A major issue to be addressed in the environmental footprint assessment in Thailand is to develop an environmental inventory database to cover all industrial sectors for the product level, in the country using the IOA method. For the social aspect, social footprint assessment will help us to understand how products and services relate to negative and positive social impacts. It can provide information on products and services that can become more sustainable from the social point of view. It is necessary to develop the social inventory database, however there is no social database in Thailand to cover all economic sectors due to the current life cycle inventory (LCI) database not covering the social aspects. In addition, it is critical to develop a characterization factor for the assessment of social impacts at a country level, to take into account the social issues in the country.

The aim of this study is to develop a social and environmental inventory database for Thailand using an input–output analysis and to formulate a characterization factor for social impact assessment that reflects the occupational health issues in Thailand. The ultimate goal of the study is to identify the environmental and social hotspots at the sectoral and products level based on the environmental and social footprint assessment.

Methods and scope: This study uses the input-output analysis (IOA) to establish the environmental and social footprint database for Thailand. The scope of the environmental inventory database includes the quantity of greenhouse gases (CO_2, CH_4, and N_2O), SO_2, NO_x, and particulate matter (PM10), within a country covered 180 industrial sectors using the 2005 Thailand input–output table (THIO). Direct air emissions related to energy have been calculated using the 2005 energy statistics database of Thailand and emission factors (EF) are based on the 2006 IPCC guidelines and the 2013 EEA guidebook. The non-energy related air emissions were also estimated based on the 2006 IPCC guidelines and the 2013 EEA guidebook. Indirect air emissions, the competitive input-output model has been applied at 180 economic sectors. The scope of the social inventory database is to cover the 96 economic sectors used in the 2005 THIO, and to consider the social impact from other countries by using the 2005 Asian International Input-Output Table (AIIO), which covers 760 economic sectors in 10 countries. The social issues considered in this study include employment (total

employment and vulnerable employment), wages, and accidents in the workplace (fatal and non-fatal cases). The statistical data for the employment in 10 Asian countries in 2005 was obtained from the IDE-JETRO. This study assumed that vulnerable employment pertains to most workers who come under the employment status groups of self-employed and unpaid family workers. In a similar way, the wages intensity of each economic sector was calculated using the data from the IO table. The statistical data for the non-fatal and fatal occupational injuries of each country were obtained from both national and International Labour Organization (ILO) databases. These databases only included formal workers as defined under the social security law of each country. For the informal worker, this study has been adjusted based on the national statistics of each country. The development of the characterization factors for social impact assessment in Thailand focused on the impact of occupational health and safety in terms of disability-adjusted life years (DALY). To validate the social inventory database, case studies on the bio-based products in Thailand such as biofuels (bioethanol, and biodiesel), and bioplastics were used.

Results: An average GHGs intensity for Thai industry, using the THIO is 2.10 ton CO_2-eq/1000 US$ with the standard deviation is 2.06 ton CO_2-eq/1000 US$. The largest GHGs intensity is in the cement sector, accounting for 16.08 tons CO_2-eq/1000 US$ that is more than double the average value about 7.7 times. Next was the cattle and buffalo sector followed by the tapioca milling, paddy rice production, and electricity generation sector, respectively. Agriculture and food–related sectors show up in eight categories out of the top 20: paddy, cattle and buffalo, swine, tapioca milling, rice milling, monosodium glutamate, coconut and palm oil, and flour and other grain milling. The GHGs intensity can be further divided by the emission type: carbon dioxide, methane, and nitrous oxide, for all sectors. Most industrial sectors are dominated by the embodied CO_2 emission. The contribution of CH_4 emission intensities is especially high in the cattle and buffalo, paddy, swine, slaughtering, tapioca milling, rice milling, coconut and palm oil. The total GHG footprints based on domestic consumption in 2005 accounted for 341 million tonnes CO_2-eq or 5.24 tonnes CO_2-eq per capita. The most important GHG intensive sector are the electricity generation sector, followed by cement, paddy, crude oil and natural gas, non-ferrous metal, and road passenger transport, respectively. In addition, the SO_2, NOx and PM10 intensity are also discussed in the study.

The average employment intensity of Thai industrial sectors using the THIO is 5.92 person/million Thai Baht with a standard deviation of 5.60 person/million Thai Baht. The highest labor intensity is in the paddy sector, followed by cassava, beans and vegetables, sugarcane, and maize and other grains, respectively. The result showed that the employment intensity in the agricultural sector has greater direct labor intensity, whereas the industrial sector has a higher share of indirect labor. Especially, food processing sectors have a greater portion of indirect labor due to the influences from the primary sector. It may be caused by the impact of food crops as raw materials. For the tertiary sector, the restaurant and bar sector showed the greatest employment intensity, followed by the hotel and guest house, medical, and sanitary services sectors, respectively. The high direct employment intensity in the agricultural sector provides the positive benefits due to actually help the rural area development in Thailand. Furthermore, the intensity of vulnerable employment, wages, and accidents in the workplace are also discussed in this study.

Based on the AIIO, an average employment intensity of Thailand is 0.17 person/1000 US$ with the standard deviation of 0.18 person/1000 US$. This value is higher than the USA, Japan, South Korea, Taiwan, Singapore, and Malaysia about 10.57, 6.49, 4.70, 3.80, 3.16, and 1.72 times, respectively. On the other hand, the employment intensity of Thailand is around 30-45% lower than in China, Indonesia, and Philippines. The highest employment intensity of Thailand is also in the paddy sector, followed by food crops, other grain, and non-food crops sector, respectively. The employment intensity of Thailand, using the AIIO, demonstrated similar trends to the results carried out by using the THIO. The result of employment footprint from final demand per capita for each country showed the share of the employment footprint is usually highest for domestic production in China, Thailand, Malaysia, Indonesia, and the Philippines, while China is always highest for imports into the USA, Japan, Singapore, Korea, and Taiwan. The developed countries (USA and Japan) dominate the top-ranking master country positions, whereas the richest Asian countries (South Korea, Taiwan, and Singapore) dominate the medium-ranking master countries. Moreover, the intensity of vulnerable employment, wages, and accidents in the workplace for each country are also discussed in this thesis.

The characterization factor for the workplace injuries in Thailand expressed in term of the DALY was 2.6 per 1000 employees or 24.30 per injury for the fatal accidents. While, the non-fatal accidents were 0.061, 1.75, 0.007, and 0.004 DALYs per 1,000 employees for the permanent total disability, permanent partial disability, temporary disability (>3 days), and temporary disability ($\leq$3 days), respectively. In addition, the average value per injury were 22.23, 3.92, 1.09×10^{-3}, and 1.99×10^{-4} DALY, respectively.

The characterization factor at sub-degree of human health loss level can provide helpful information to identify hotspots in the social footprint assessment. The social hotspots are the highest occupational accident intensity in the saw mill sector, follow by metal products, construction, non-metallic ore and quarrying mining, and home appliances sector, respectively.

The result of case studies indicated that biofuels and bioplastic production in Thailand have the positive impact in terms of employment generation and income. The total employment along the supply chain of bio-based products is higher than petroleum-based products. The direct employment in the cultivation stage created 70% more employment throughout the overall supply chain. For the wage impacts, the result showed that the bio-based products could increase the income distribution in agriculture workers in the rural area of the country. In addition, in terms of the fatal occupational injury aspects, the result presented that bio-based products have a higher impact than petroleum-based products. It should be improved by promoting and encourage the training and disseminating on the safety and health impacts in the workplace whole the supply chain.

Conclusions: Environmental and social intensities using the input-output analysis and footprint concept in Thailand, at all economic sectors, can provide baseline data for the environmental and social footprint inventory. Modified characterization factors on the human health impact developed at sub-degree of human health loss level reflecting to the occupational health and safety in Thailand can contribute to the identification and assessment of social hotspots and sustainability in terms of health and safety aspects.

It is expected that the environmental and social inventory and social impact assessment using the DALY will contribute to the improvement of health and safety impact at the product level. The social footprint inventory developed in this thesis is relevant at both the national level and Asian countries level. The DALY in this study is concerned with human health effects caused by accidents in the workplace. This is a preliminary study on DALY issues as a first step. Further works on other social impact categories and environmental impact assessment need be carried out to complete the social and environmental footprint assessment.

Chapter 1: Introduction and objectives of the study

1.1 Background

Since the first national economic development plan in 1961, the economic policy of Thailand focused on industrial development. As highlighted by its investments in the physical structure, transportation, communication and public utilities in order to determine the industrial zones and announced the measurements required to promote industrial investment. At the same time, apart from in industrial development, there are other costs besides business spending that includes damage to human health and natural resources. This is especially the case in relation to ecosystem damage and including environmental costs. The severe increase took place when the heavy and downstream industries were established and expanded. The policies and measures to promote industry in Thailand can attract domestic and foreign investment, coupled with cheap labor and location of industry area. However, the management of natural resources and the environment has received little attention compared to the dedication to expanding industry (NESDB, 2015).

The environmental movement in various regions of the world has resulted in Thai people starting to pay attention to the environmental issues within the country. For instance, the Thai government announced the first Enhancement and Conservation of National Environmental Quality Act in 1975 (Office of policy and planning and natural resources, 1975), and the country began to use the first environmental conservation development plan in the fourth national economic and social development plan (1977–1981). The seventh national economic and social development plan (1992–1996) covered specific concerns about the impact on the quality of life for people's lives and that of the community, which is considered to be a limitation on future economic development. Over 50 years (1961–2015), in the development of the national economic and social development plan, the industry–driven results were mostly concerned with issues causing damage to the environment and society. There are included the loss of natural resources, degradation of environment quality, air pollution problem, water quality loss, health and safety of the workplace, etc.

At present, the world is interested in the importance of creating a balance between economic development, society and the environment due to how many countries are affected by the severity of climate change. For example, the occurrence of droughts in many areas and many countries around the world result in severe water shortage in consumer. It's also going to affect the quality of life in human society. Developed countries have introduced measures of nontariff-barriers. Corporate social responsibility (CSR) is one of the issues used in the purchasing of goods and services, from producing countries, in particular developing countries, where the manufacturers must be adaptable to be able to maintain the export markets. In addition, they will need to produce quality products by maintaining the environmental and social quality. In the near future, there will be a need to strive towards sustainability in three main areas based on the life cycle perspective, namely economic, social and environmental. Because the environmental and social impacts of products play the increasingly important role in international trade and influence buying decisions of consumers, companies, and public bodies. Life cycle assessment (LCA) has been found to be the most advanced approach that can quantify these impacts. However, an evaluation of economic, social, and environmental indicators is required to use the life cycle inventory (LCI) database to quantify these indicators.

In Thailand, the National Metal and Materials Technology Center (MTEC) under the National Science and Technology Development Agency (NSTDA), has developed the Life Cycle Inventory (LCI) database of the basic materials and energy in the country. The target of this database is to be used to support the planning and implementation of environmental policy, and to promote the carbon footprint scheme. However, the LCI database is based on a process-based approach has extensive data requirements, making it expensive and time consuming. It also does not account for all the direct and indirect economic interactions that will take place. Nevertheless, this LCI database can be applied only the greenhouse gas (GHG) aspect due to lack of data on other aspects. While for the social database, there is a variety of qualitative information available and lack of the quantitative database.

The most important topic in the study is how to develop the environmental and social footprint database, within a country, based on input–output analysis (IOA) approach due to the lack of database. In addition, to develop the characterization factors for occupational health and safety in Thailand, it covers both fatal and non-fatal occupational injuries in the workplace that reflect to the occupational health in the country.

1.2 Issues on Environmental LCA

The manufacturing of any products and services (including their usage and disposal) require natural resources, materials, energy and all generate emissions that enter into the environment (soil, water and air) impacting on the environment in various ways. A method to estimate the environmental impact that occurs in many ways and one of the ways recognized and most widely used is throughout the life cycle assessment or (LCA). LCA is a method of assessing the environmental impact of the resources used during the entire life cycle by considering everything from the raw material acquisition, manufacturing, transport, use, and disposal. An LCA will take into account all aspects of the effects on human health, ecosystem quality, and resources depletion. In addition, an LCA can also be used to analyze the strengths–weaknesses in the production process, planning in the use of resources, policy making, and environmental labelling, such as, the Carbon Footprint (CF) labeling (Japan, Thailand Korea, United Kingdom, etc.), Environmental Product Declaration (EPD) in Sweden, Eco-Leaf labeling in Japan, and the Product Environmental Footprint (PEF) in European.

For the sustainable development goals in Thailand, the environmental issues are very important aspects that should be clearly addressed in the environmental footprint assessment. A major issue to be addressed in the environmental footprint assessment in Thailand is to develop an environmental inventory database to cover all industrial sectors for the product level in the country. Although, Thailand has developed the national LCI database for several years, but it can be applied only the GHG assessment, and does not cover all the important economic sectors in the country. Therefore, the development of an environment inventory database by using the IO model will fulfill a national LCI database that is still lacking the data.

1.3 Issues on Social LCA

Social LCA is a method of evaluating the social and socio-economic impacts or potential impacts of products and services, both positive and negative, impact throughout the entire life cycle. However, the lack of quantitative data about social issues are the weakness of the social LCA applications. In addition, when assessing the social impacts of an LCA there are no common units, no standard methods to evaluate the social impact, a lack of database availability, and it can be time consuming and expensive to collect data. Many social indicator are also perceived subjectively.

The social issues are an important aspect in the sustainability assessment of any product and service. Social aspects should be clearly addressed in the social footprint assessment. A major issue to be addressed in the social footprint assessment in Thailand is the development of a social inventory database to covers all economic sectors for the product level social footprint assessment and impact assessment factors reflecting the occupational health and safety in Thailand as a basis for an assessment of the concept of social footprint scheme and its impact.

Social footprint assessment will help us to understand how products and services related to negative and positive social impacts. It can provide information on products and services that can become more sustainable from the social point of view. It is necessary to establish the social inventory database for the assessment, however there is no database in Thailand to cover all economic sectors due to the current LCI database could not cover social footprint aspect. In addition, it is critical to develop a characterization factor for assessment of social impact at country level to be taken into account social issues in the country.

1.4 Objectives of the study

The aim of the study is to develop a social and environmental inventory database for Thailand using an input–output analysis and to formulate a characterization factor for social impact assessment that reflects the occupational health issues in Thailand. The scope of the environmental inventory database includes the quantity of greenhouse gases (CO_2, CH_4, and N_2O), SO_2, NO_x, and particulate matter, within a country covered 180 industrial sectors using the 2005 Thailand input–output table.

The scope of the social inventory database is to cover the 96 economic sectors used in the 2005 Thailand Input-Output table (THIO), and to consider the social impact from other countries by using the 2005 Asian International Input-Output Table (AIIO), which covers 760 economic sectors in 10 countries. The social issues considered in this study include employment (total employment and vulnerable employment), wages, and accidents in the workplace (fatal and non-fatal cases). The development of the characterization factors for social impact assessment in Thailand was focused on the impact of occupational health and safety in terms of disability-adjusted life years (DALY). The scope of the environmental and social inventory database, and social impact assessment method in this study are presented by the dotted line in Figure 1-1. To validate the social inventory database case studies on the bio-based products in Thailand such as biofuels (bioethanol and biodiesel), and bioplastics were used.

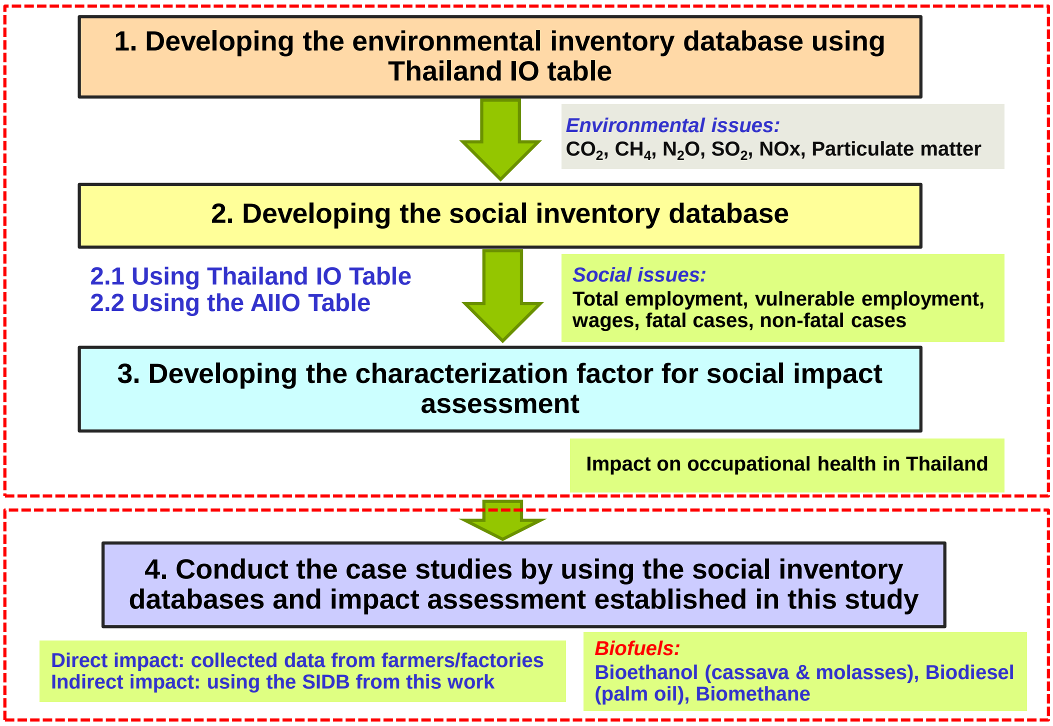

Figure 1-1. Scope of this study for environmental and social footprint inventory development and social impact assessment

1.5 Structure of the thesis

Chapter 1 introduces the background and objectives of the study. Chapter 2 provides theory, literature reviews, and the method. Chapter 3 explains the details of the development of an environmental inventory database using Thailand's input-output table in all the 180 economic sectors. The inventory issues include greenhouse gas (GHG) emissions, SO_2, NO_x and particulate matter. Chapter 4 explains the details of the development of a social inventory database using Thailand an input-output table at all the 96 economic sectors. The social issues related to total employment, vulnerable employment, wages, fatal, and non-fatal occupational injuries. Chapter 5 illustrates the details of the development of a social inventory database using the Asian International Input–Output table of all 760 economic sectors within 10 countries. Chapter 6 contains the developed characterization factors for the occupational health of Thai workers. Chapter 7 introduces case studies using the social inventory database and characterization factors. Chapter 8 concludes the thesis with recommendations and limitations of the study. This study can be applied not only to estimate social footprint assessment, but also to calculate the social footprint at national level.

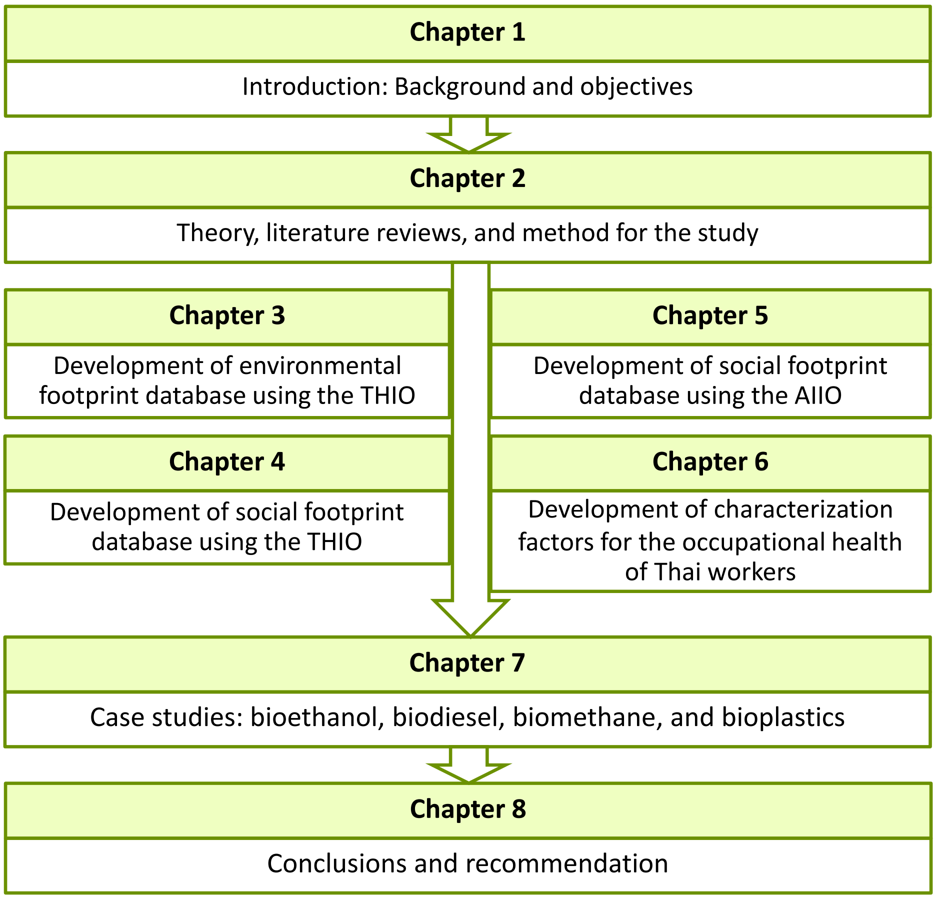

Figure 1-2. The framework of this study.

Chapter 2: Method and Literature Reviews

2.1 An Environmental Life Cycle Assessment

2.1.1 The Environmental Life Cycle Assessment Framework

An environmental life cycle assessment (E-LCA) is a method for evaluating the environmental aspects of a product and their potential environmental impacts associated with a product's life cycle. The product refers to both goods and services, including the raw material acquisition, manufacturing, use, and disposal (ISO, 2006). Figure 2-1 shows the life cycle stages in the LCA study that can be considered in an LCA and the typical inputs and outputs measured.

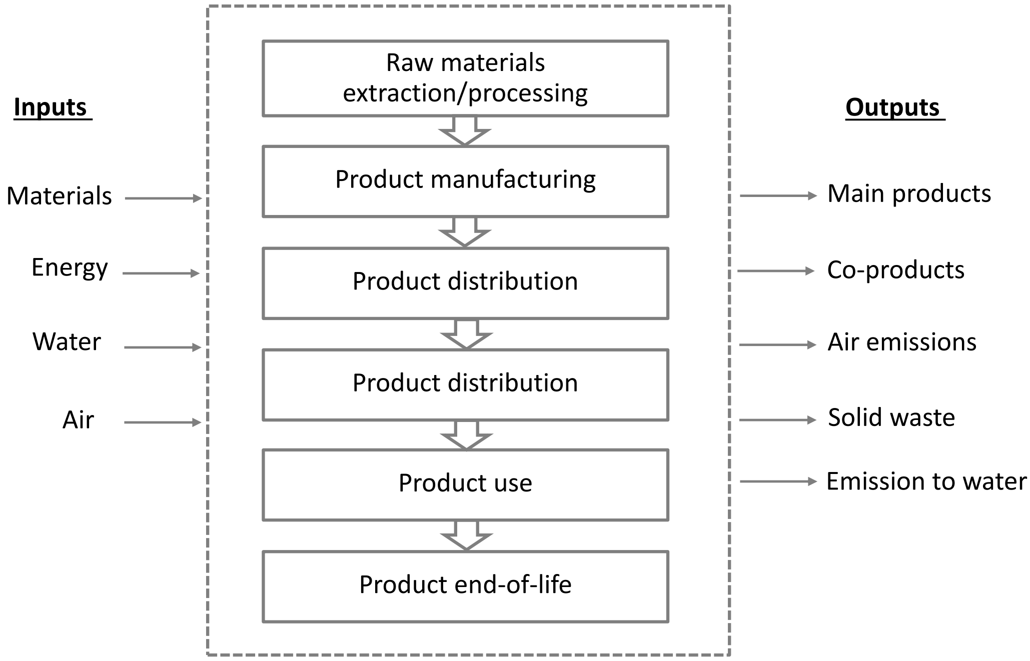

Figure 2-1. The life cycle stages of LCA study.

The method of LCA is now being standardized in relation to the ISO 14040 series. According to ISO 14040 (ISO, 2006) the LCA framework consists of 4 steps: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation, as presented in Figure 2-2.

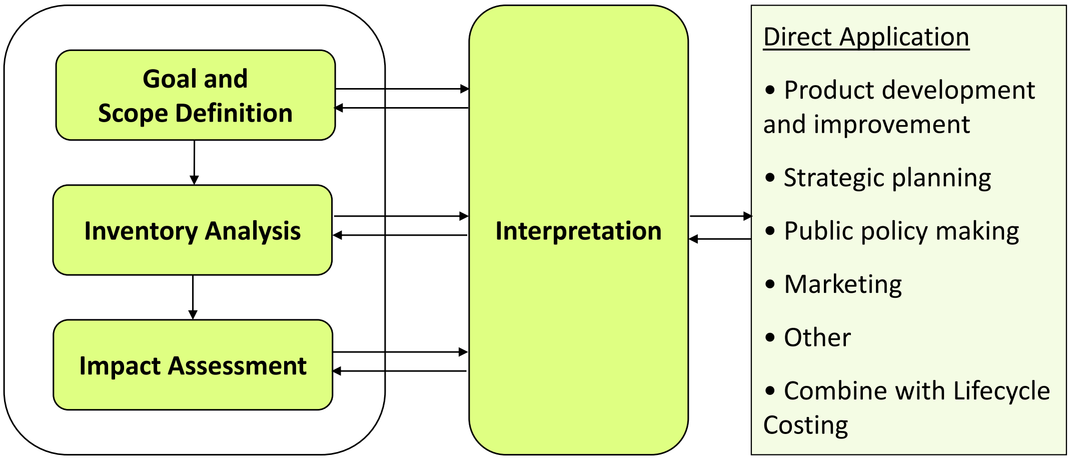

Figure 2-2. Steps of LCA framework based on ISO 14040 (ISO, 2006).

2.1.1.1 Goal and scope definition

The main objective and application of this step aimed to communicate the results to the intended audiences. These are very important because they set the alternative methods to consider in the study. In addition, the study results also depend on the aim and the question set up directly on the defined target. The step of goal and scope defines the functional unit of the product or service that are of interest in the study. The functional unit is the function of the system or product to quantitatively evaluate, and assist in the comparison of, different products by the same functional unit. The system boundary is defined in terms of the temporal and geographical parameters including the cut–off rule and the allocation method. Each element in the first stage can help determine the scope of the system under the study. The environmental impact categories and impact assessment methods are also defined in this stage (ISO, 2006).

2.1.1.2 Inventory analysis

This step will focus on identifying and determining the mass and energy flow associated with environmental system. In relation to ISO 14044, the first activity in this stage is to create process flow diagrams to identify flows involved all of the input materials and resource use, and the output of both emissions and waste within the boundary of the system, and between the system and environment. The next step is determining the quantified flows and to adjust the quantity of the reference unit, which is determined by the functional unit. This is one of the aspects of LCA methodology that must be executed during the analysis of the inventory data that are created by problems with multiple functions in the system. If the various systems need to divide the environmental burden–sharing of each product, as well as this, for processes that have more than one substance in the input phase, it is necessary to know how to allocate the environmental load of the systems to each of the inputs. The ISO 14044 recommend that to deal with this situation the collection of more detailed information needs to be extracted to separate subsystems. In the event that this is not compulsory, replacing or expansion of the system should be employed. This refers to the system of benefits for any of the functions provided by the system. There are also main functions under the LCA study and in cases these methods cannot be performed, allocation or sharing can be used which means distributing the impacts among the products in accordance with their physical properties, or market value (ISO, 2006).

The development of environmental inventory data in an LCA will depend on two different important approaches, the process–based approach and input–output analysis (IOA) approach. The process–based method starts with quantifying the flows of mass and energy within the scope of the system. The input–output methods will depend the flow of the economy within the country's industry sector. Normally, the IOA in an LCA starts with economic data collected by the national statistical agencies, which explains the level of transactions among industrial sectors. By expanding the data relating to the environmental burden of each sector, the analyst can assess the impact of all economic sectors resulting from the purchase of goods from other sectors. A key challenge of the process-based method is that it takes a long time to get the relevant information for the LCA study. While, the IOA method requires less effort to obtain the relevant information and to reduce the risk of neglecting the other elements of the system. There is also a risk of below–estimating the environmental impact related to the products, especially those resulting from the use of average emissions for each economic sector. With the choice between both methods, the hybrid approach that combining the process-based and IOA-based methods seem to be the better alternative with an acceptable level of uncertainty, depending on the goals and scope of the study.

2.1.1.3 Life cycle impact assessment (LCIA)

In this step, the environmental data from the inventory analysis step will be converted into the value of the environmental effect. The activities in this step consist of: classification, characterization, and weighting.

The classification stage is identified by the inventory data into the related environmental impact categories, such as global warming, fossil fuel depletion, acidification, eutrophication, and human toxicity potential. The characterization stage calculates the results of each impact category using the conversion factors, such as, the importance of greenhouse gas emissions from the products is expressed in terms of the impact of the radiation force on the planet in the equivalent unit mass of carbon dioxide. This impact is one of the midpoint indicators, which is the middle position of the cause-effect sequence amongst the pollutant releasing aspects and the adverse consequences that occur. These include the impacts on human health through to increases in the effects of flooding, diseases, and heat stress. Apart from the effects on human health, the endpoint impact on natural resources and ecosystem should be considered in this step (Figure 2-3).

Weighting and normalization are the optional procedures for indicating the most important impacts. Normalization calculates the importance of the impact associated with the reference value. Weighting allows the combined value of the endpoint impact, results that were affected by several indicators went into a single index. There are many different approaches to the deferent methods of weighting, such as ReCiPe (Goedkoop et al., 2009) or EDIP (Bauman & Tillman, 2004), which can be used to sum the results into a single value.

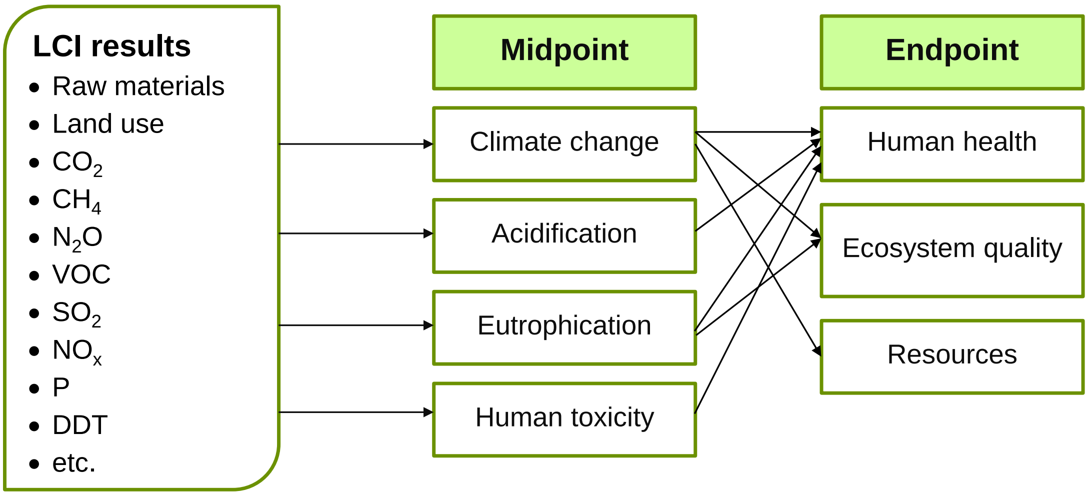

Figure 2-3. Framework of LCIA method.

Source: modified from ISO (2006)

2.1.1.4 Interpretation

Due to the face that the LCA is emphasized, interpretation of each step is highly important. This can result in the improvement in each procedure, and the results of the life cycle impact assessment would be interpreted in accordance with the goals and scope of the study. Analysis on the quality of data along with sensitivity analysis or uncertainty analysis, can be used to check the validity of the LCA results.

2.1.2 Application of the E-LCA

There have been many E-LCA studies around the world and most have focused on the greenhouse gas emissions based on the process-based analysis. Examples of E-LCA studies on biofuel are as follows:

Xunmin et al. (2009) presented an LCA study on the energy consumption and GHG emissions of China's current six biofuel pathways, which are: corn-derived ethanol; cassava-derived ethanol; sweet sorghum-derived ethanol; soybean-derived bio-diesel; jatropha fruit-derived biodiesel; and used cooking oil-derived bio-diesel. The tool utilized was the WTW module of Tsinghua-CA3EM model covering the entire lifecycle including: the raw materials cultivation, fuel production, transportation, and distribution. This work was applied to automobile engines and compared with conventional petroleum-based gasoline and diesel pathways.

Walter et al. (2011) studied the sustainability of sugarcane ethanol in Brazil. The goal of the study is to assess the sustainability of sugarcane ethanol in three aspects: direct land use changes, GHG emissions and socio-economic aspects at the level where the production takes place. The study focused on the sugarcane and ethanol production in the states of São Paulo and Mato Grosso. The boundary of GHG balance in ethanol production accounted from the sugarcane agricultural to ethanol distribution. In Land use change, carbon changes are considered based on the IPCC methodology (IPCC, 2006). For socio-economic impact, the analysis focused on the indicators from the Human Development Atlas of 1991 and 2000 (UNDP, 2008).

Khatiwada et al. (2012) studied on the GHG emissions of sugarcane ethanol production in Brazil. The study focused on four regulatory schemes; European (EU-RED and UK-RTFO) and American (US-EPA and CA-CARB); which were designed to account for the life cycle GHG emissions in relation to the Brazilian sugarcane ethanol production. The boundaries were related to the direct life cycle and indirect land use changes in emissions.

Moriizumi et al. (2012) was examined to identify the best option with respect to the life cycle greenhouse gas (GHG) emissions reduction of five types of cassava ethanol factories in Thailand: (1) stand-alone ethanol factory, (2) stand-alone ethanol factory using biogas for steam generation, (3) stand-alone ethanol factory using biogas for electricity generation, (4) ethanol factory co-located with a cassava starch factory using biogas for steam generation, and (5) ethanol factory co-located with a cassava starch factory using biogas for power generation.

Silalertruksa and Gheewala (2012) conducted the case studied on the environmental sustainability assessment of palm biodiesel production in Thailand compared to diesel. The scope of the product ranges from the oil palm plantation stage to the production of biodiesel.

The system boundary is cradle to gate including the on-site waste management. The research focused on resource usage in relation to the land occupied, and the air and water emissions.

2.2 Social Life Cycle Assessment

2.2.1 Social Life Cycle Assessment Framework

Social or Socio-Economic Life Cycle Assessment (S-LCA) is a method of evaluating the social and socio-economic impacts of the positive and negative impacts of the entire life cycle of products or services (UNEP, 2009). Similar to the environmental LCA, the life cycle phases of the supply chain of a product are investigated in the S-LCA, including the raw material extraction and processing, product manufacturing, distribution, use and disposal. In each phase the impacts on each of the different types of stakeholders are assessed. The results of an S-LCA are used to communicate social performances to stakeholders. The discussion of integrating social issues as part of an LCA began in the 1990s due to the S-LCA methodology having advanced to a point where it resolves some issues regarding the environmental LCA. The United Nations Environmental Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) have published guidelines for the S-LCA. There have been many social LCA case studies that have been based on the UNEP/SETAC Guidelines for Social Life Cycle Assessment of Products (UNEP, 2009). Almost all social issues addressed in the S-LCA case studies assessed the social impacts in terms of a qualitative and semi-quantitative approach. In this regard, there is a lack of data on the social inventory of many social indicators. Social indicators in terms of quantitative, qualitative and semi-quantitative are issued in the UNEP/SETAC guidelines for a social LCA. The social inventory includes five stakeholder groups: workers, local communities, consumers, society, and value chain actors. The S-LCA framework proposed by UNEP is presented in Figure 2-4 (UNEP, 2009). According to the UNEP/SETAC guidelines, the S-LCA method is developed based on the environmental LCA method that is explained in Section 2.1. It is a similar way to include four steps: goal and scope definition, inventory analysis, impact assessment, and Interpretation.

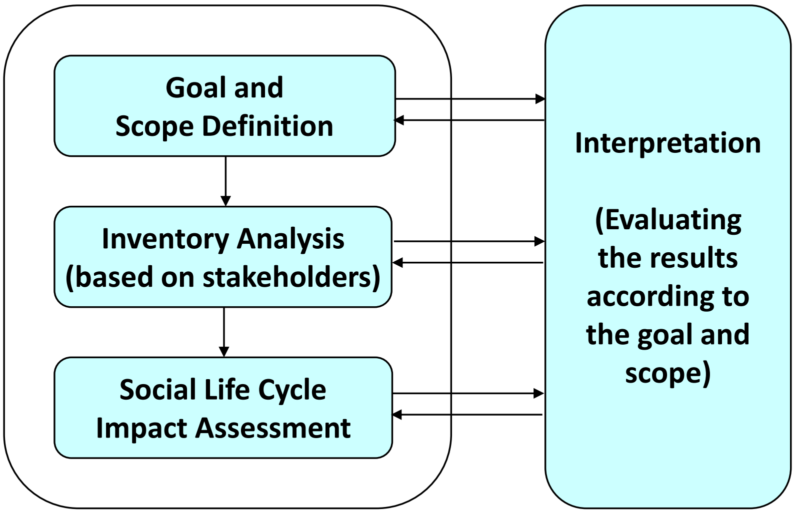

Figure 2-4. The S-LCA framework proposed by UNEP (UNEP, 2009).

2.2.2.1 Goal and scope definition

Firstly, the initial stage is required when performing an S-LCA is necessary to define the goal clearly. This statement describes the intended usage in order to get results, as the goal purposed. The planning of various restrictions, depending on the goals that are defined as critical, may be required. The second stage is to define the scope, which is part of defining the scope of the function and the functional unit that will be used to assess the products. On the basis of the information of the product system would be modeled the input–output data. In this step, the study should be defined and decisions about which unit processes required to collect the generic or specific data. To determine the depth of a study, variable activities (such as hours or value added) may be applied.

The goal and scope steps comprise of the following activities:

- Specification of the destination and purpose of the study (including the goal, function of the product, functional unit, etc.).
- Definition of the activity monitoring variables that are used and the unit processes that are included in the estimation.
- Planning the data collection and defining the data that is going to be collected, including the types of impact categories and subcategories that would be selected in the study.
- Identification of the stakeholder groups associated with each process and the type of critical reviews that are desired. The example of subcategories and stakeholders based on the UNEP/SETAC guidelines are presented in Table 2-1.

Table 2-1. Stakeholder categories and subcategories for S-LCA

Stakeholder	Subcategories
Worker	Freedom of Association and Collective Bargaining; Child Labour; Fair Salary; Working Hours; Forced Labour; Equal opportunities/ Discrimination; Health and Safety; Social Benefits/Social Security
Consumer	Health & Safety; Feedback Mechanism; Consumer Privacy; Transparency; End of life responsibility
Local community	Access to material resources; Access to immaterial resources; Delocalization and Migration; Cultural Heritage; Safe & healthy living conditions; Respect of indigenous rights; Community engagement; Local employment; Secure living conditions
Society	Public commitments to sustainability issues; Contribution to economic development; Prevention & mitigation of armed conflicts; Technology development; Corruption
Value chain actors (not including consumers)	Fair competition; Promoting social responsibility; Supplier relationships; Respect of intellectual property rights

Source: UNEP (2009)

2.2.2.2 Inventory analysis

The inventory is the second step of the S-LCA and includes: creating the process flow of the product systems, and collecting the inventory data. The inventory analysis step comprises of the following activities:

- Prioritization and screening of the data collection that is required and possibility of the data that will be obtained. For example, the employment (worker hours) and wage rates should be considered in the study.
- Analyzing the overview of the social problems in the interested area, that is related to the product's life cycle.
- Preparing the main data collection in order to develop the questionnaires for gathering the information that is required in the study.
- Main data collection – the site-specific data is being continually gathered via social audits, interviews or questionnaires, etc., which relate to the interested organization and the relevant stakeholders. Generic data are obtained from the national statistic agencies and international organizations.
- Validation of data is checked to confirm its quality and provide evidence based on those requirements.
- Relating data to the functional unit and unit process, the quantitative input and output data of the unit process shall be calculated in relation to the functional unit.

2.2.2.3 Impact assessment

The S-LCIA can be conducted based on the environmental LCA study as shown in Figure 2-5. The impact assessment consists of four steps: classification, characterization, normalization and analysis of data quality.

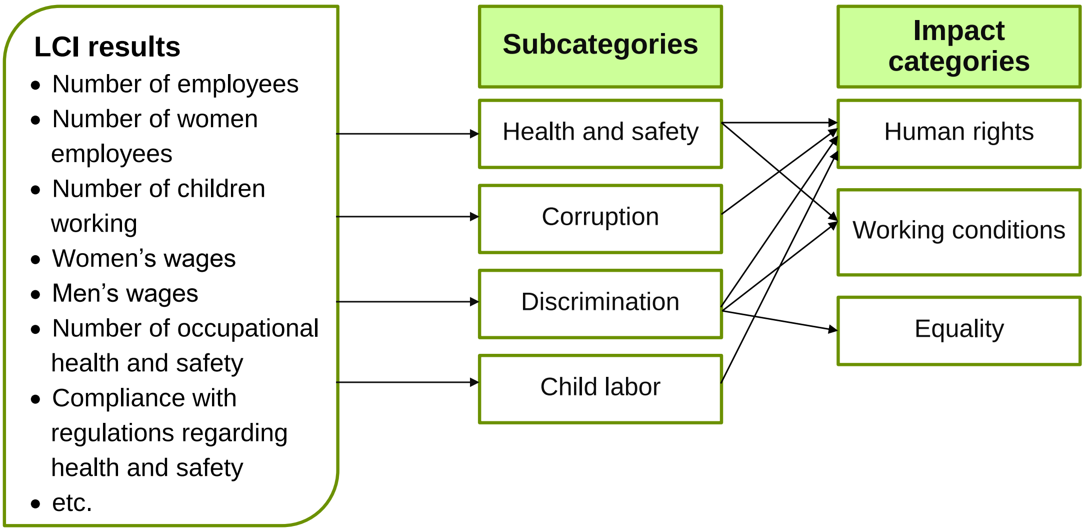

Figure 2-5. Framework of social LCIA method.

Source: modified from UNEP (2009)

1) Classification

This step classifies the individual social aspects into a group of social indicators. For example, various types of jobs could be related to various modes of employment, such as full–time or part–time workers, paid workers, self-employed workers, etc.

2) Characterization

The inventory results (number of jobs, job satisfaction, etc.) cannot be simply aggregated, but require checks to be made that the results have the same or different weightings. Such as, the outcome of the full-time jobs is allocated to 100%, whereas the part-time jobs are allocated a value of 50%. One method of managing this would be to set weightings for the jobs (such as 1.0 and 0.5) and then to aggregate they based on this weighted approach. In addition, the qualitative analysis, such as the quality of jobs, needs to be applied.

3) Normalization (optional step)

Normalization is an optional step that is only appropriate with quantitative results. The outcomes from the normalization step will reflect the significance of the different impact categories in relation to the reference system. If we applied the S-LCA by combining it with the E-LCA and life-cycle costing, the reference system should conform to them all.

2.2.2.4 Interpretation of results, and evaluation

Based on the LCA standard method, the interpretation of the results from the S-LCA is to check the completeness, consistency, and sensitivity, including the relevant information and associated stakeholders. The results from society aspects should be used as the alternative option for improving the social performance of the product system. The evaluation process consists of the critical review of performance, involvement of stakeholders, documentation, transparency and confirmation of results, and the sensitivity analysis.

2.2.2 Application of S-LCA

There have been many social LCA studies around the world and many social issues proposed based on the ILO point of view. Examples of social LCA studies are as follows:

Dreyer *et al.* (2006) proposed a framework for social LCA focusing on the fundamentals of universal criteria and company relevance. In respect of the social aspect, the proposed area of protection is “Human Dignity and Well-being”. The S-LCA framework consists of two levels of impact categories—mandatory and optional. The method combines the bottom-up and top-down approach. In the bottom-up approach, relevant social issues from the company’s point of view should be considered. For a top-down approach, the parameters that identify what is valuable to society, which are relevant from a societal point of view, are assessed. In addition, six case studies were used to confirm the applicability and feasibility of the inventory and characterization steps of the method (Dreyer, 2009).

Benoit-Norris *et al.* (2012) presented an overview of the social hotspots database (SHDB) development and features. The SHDB was developed over three years as a follow-up to the UNEP/SETAC guidelines for an S-LCA. It provided characterization indicator data for 191 countries and multiple sectors. The data were collected from over 200 data sources, mostly international organizations’ databases.

Macombe *et al.* (2013) analyzed the possibilities and development needs for evaluating the social impacts of a biodiesel case study. The analysis focused on three levels: company, regional, and state levels. The conclusion shows that in many cases it is not yet possible to carry out an S-LCA. The S-LCA at various levels would improve the methodology on an empirical basis.

Hutchins *et al.* (2013) provides a framework that uses the process-based approach to characterize and identify key characteristics of social impacts associated with manufacturing throughout the life cycle of the product. Social impacts occur on various scales in manufacturing, from the level of a unit process to the level of the enterprise.

Martínez-Blanco *et al.* (2014) performed an S-LCA case study of fertilizer production and application in cultivation. The method selected in the study was based on the UNEP/SETAC S-LCA guidelines and the social hotspots database (SHDB) to include social aspects related to the background processes. The assessment was based on three geographical scales: country, sector, and company scales. In conclusion, the social indicators could be aggregated throughout the life cycle of the system. However, this approach could not be employed at a company scale because data at this level are difficult to obtain for the entire life cycle.

2.3 Input-output analysis

Process-based LCAs, economic input-output LCAs (EIO-LCA), and hybrid LCAs are the most widespread LCAs approaches in the literature. However, the application of an EIO-LCA in Thailand is limited by the availability of statistical databases and the type of products or services in sub-sectors in the economic input-output table. In addition, the lack of statistical data on sectoral energy consumption, environmental emissions, and social issues are barriers to an EIO-LCA application in Thailand. Thus, it is difficult to develop a satellite matrix in the input-output (IO) model.

The input-output model was developed by Leontief in the 1930s. The application of the IO model to a study on the environmental aspects was conducted from late 1960s and early 1970s (Leontief, 1970). Input-Output Analysis (IOA) has often been used to develop inventory analysis in LCA studies. Databases on IOAs have been widely used in life cycle inventory and assessment studies (CMU, 2009). In Input-output (IO) tables, transactions of goods and services amongst the industrial sectors are presented in matrix form and expressed as a monetary value. Energy and resource flows can be analyzed on the assumption that goods are transferred in direct portion to their monetary value. So IO tables have been widely applied to the area, particularly for environmental analyses (Asakura et al., 2001; Hondo et al., 1998, 2002). Recently this method has been applied in the environmental field such as energy use and CO_2 emissions (Nansai et al., 2002; Nojiri, 2011).

However, there are many case studies around the world on the social impact analysis using an IO analysis (IOA). Almost all case studies are only focused on an employment analysis; for example, Garrett-Peltier (2010) evaluated the employment impacts of renewable energy investment in the US; Martinez *et al.* (2013) assessed the social impact in terms of employment for sugarcane-ethanol in Brazil; Chen *et al.* (2013) looked at oyster farming in Taiwan; Tang *et al.* (2013) examined Chinese petroleum industry; Lee and Yoo (2014) evaluated the fisheries and aquaculture sectors in Korea; Ferrao *et al.* (2014) addressed the packaging waste management system in Portugal; McBain, D. and Alsamawi, A. (2014) assessed labor in global trade using multi-regional input–output analysis; Malik *et al.* (2015) addressed the employment issue in lignocellulosic biofuel production in South Australia; Yang *et al.* (2015) evaluated the employment impact pf algae-derived biodiesel in China. There are two case studies the concentrate on two social issues, such as Kucukvar *et al.* (2014) who focused on income and work-related injuries for a social sustainability assessment in US, and Alsamawi *et al.* (2014) focused on the employment and income footprint of world's nations. There are some case studies concentrated on many social issues such as Chang (2011) who focused on accidents, fatalities, employment, research and development personnel, science and technology (ST) personnel, and funding for ST activities for a construction project in China. Onat *et al.* (2014) addressed the social impacts in terms of income, government tax, and injuries in the US building sector, using an IO analysis. Simas *et al.* (2014) addressed the six negative labor footprints, which consist of occupational health damage, vulnerable employment, gender inequality, share of unskilled workers, child labor, and forced labor associated with consumption in the seven world regions. Gómez-Paredes *et al.* (2015) focused on six labor issues including collective bargaining, forced labor, child labor, gender inequality, hazardous work, and social security, for an Indian case study.

2.3.1 Concept of Input-Output Analysis

The basic concept of the IOA that have been applied in this research and discussed in detail by Leontief (1966). However, the main equations are briefly restated below.

Let Y is a vector (n x 1) of the final demand from industry sectors $i = 1, 2, \ldots, n$ and X_{ij} is the elements of a matrix (n x n) of intermediate demand of industries $j = 1, 2, \ldots, n$ from industries $i = 1, 2, \ldots, n$. The total (intermediate plus final) demand X_i from industry i is then

$$X_i = \sum_{j=1}^{n} X_{ij} + Y_i \qquad (2.1)$$

where A is a matrix (n x n) of technical or direct input coefficients a_{ij}, which relates to output X_j of industry j to its inputs from industries i by

$$X_{ij} = a_{ij} X_j \qquad (2.2)$$

so that the matrix notation equation (2.1) becomes

$$X = AX + Y \tag{2.3}$$

Solving for X yields

$$X = (I - A)^{-1} Y \tag{2.4}$$

where I is the identity matrix (n x n) and $(I - A)^{-1}$ is called the Leontief inverse matrix. Since

$$(I - A)^{-1} = I + A + A^2 + A^3 + ... \tag{2.5}$$

the total output X can be written as

$$X = Y + AY + A^2Y + A^3Y + ... \tag{2.6}$$

The relationship between production and consumption tables, technology matrices, final demand, value added, and the emissions and resources are shown in Table 2-2.

Table 2-2. The overall structure of an environmentally and socially extended input-output framework.

	Input to sectors (j)				**Intermediate output *O***	**Final demand *Y***	**Total output *X***
Output from sectors (i)	1	2	3	n			
1	X_{11}	X_{12}	X_{13}	X_{1n}	O_1	Y_1	X_1
2	X_{21}	X_{22}	X_{23}	X_{2n}	O_2	Y_2	X_2
3	X_{31}	X_{32}	X_{33}	X_{3n}	O_3	Y_3	X_3
n	X_{n1}	X_{n2}	X_{n3}	X_{nn}	O_n	Y_n	X_n
Intermediate input *I*	I_1	I_2	I_3	I_n			
Value added *V*	V_1	V_2	V_3	V_n		**GDP**	
Total input *X*	X_1	X_2	X_3	X_n			
Employment and social issues	*Social flow matrix S*						
Resources and emissions	*Environmental flow matrix E*						

When emissions, resource use or other environmental/social indicators are investigated, they can be included in the environmentally and socially extended input-output analysis. The environmental flow matrix is divided by the industry output to get the emission/resource intensities:

$$e = E / X_j \tag{2.7}$$

where, e is the resource use or emission intensity (environmental flow by industry) [kg/million Thai Baht], E is a vector of resource use or emissions (environmental flow by industry) [kg].

Re-arranging equation (2.4), and introducing a vector of resource use or emission coefficient, we obtain the resource use or emission coefficient with the inverse form of equation (2.4) as equation (2.8):

$$f = e\,X = e\,(I - A)^{-1}Y \tag{2.8}$$

where, f is the total resource use or emissions caused by final consumption Y; $e = [e_1, e_2, \ldots, e_n]$ is a (k × n) row vector of resource use or emission coefficients by sector. $e\ (I - A)^{-1}$ is the environmental multiplier (footprint) matrix.

2.3.2 Environmental inventory database using an Input-Output Analysis

The evaluation of energy consumption and environmental impacts is necessary to use appropriately the environmental tools, in which one of the assessment tools to assess the environmental effects of throughout the entire life cycle of products or an LCA. But the restrictions in the life cycle inventory data of a product, results in many groups of LCA researchers raising the application of LCA by using the Input-Output Analysis (IOA) technique.

At present, there are IO table applications widely used by economists and scientists from various disciplines, including the use of the database to develop a model for the study of energy demands for the economic system. To evaluate the environmental impact, in particular the use of IO tables applied to the LCA study, and developed the life cycle inventory database, such as GHG Inventory, water footprint accounting, land use footprint, etc., can be applied the IOA technique.

Ono et al. (2015) developed the water footprint database of the production of goods and services in Japan, through the use of IOA techniques. The 403 economic sectors were investigated, the results demonstrated that the intensity of the input water and water consumption in the primary sector was very high value and dependent on rainwater. While the water intensity of the secondary sector has a higher value than in the tertiary sector. The water footprint database can be applied to evaluate the water footprint of products, services, and enterprises in Japan.

Hienuki et al. (2015) evaluate the effects on the environmental and social of the electricity generation technology in potential future scenarios of Japan. The analysis applied the hybrid IO techniques to forecast the GHG emissions, and the employment generation of the power systems in Japan between the years 2012-2030.

Zhang and Anadon (2014) applied the multi–regional input–output analysis (MRIO) to estimate the water footprint and virtual water at the province level in China. In 2007 the level of water withdrawals and water consumption in the country, represented 184 billion m^3 and 101 billion m^3, respectively. There are four large footprint cities in Beijing, Shanghai, Tianjin and Chongqing where the water footprint per capita are high. While in provinces that water in the lower require the external water from other provinces to support their water consumption.

Zhang et al. (2014) evaluated the non-CO_2 GHG emissions (CH_4, N_2O, HFCs, PFCs and SF_6) in 2005, in China, using an IOA. They found that the direct non-CO_2 GHG emissions, representing 1,368.5 million tonnes CO_2-eq, came from 848.4 million tonnes of CH_4 emissions, 356.8 million tonnes N_2O and 163.3 million tons of other gases. Approximately 93.2% of total pollution comes from the agriculture, coal mining, and chemical sectors. The quantity of embodied emissions that are exported as goods from China representing 487.0 million tonnes CO_2-eq, of which 35.6% comes from the textiles and clothing, and leather products.

Bouasan and Vorayos (2013) applied the IO table in Thailand in order to evaluate the energy consumption and air pollution, including CO_2, CH_4, N_2O and SO_2, in the agriculture sector. They estimated the air pollution based on the 2006 IPCC guidelines combined with fuel consumption of each economic sector. All the information used in the analysis was based on 2005 values. In addition, they also estimated the GHG emissions of non-energy related activities, such as livestock, degradation of organic compounds in rice fields, etc.

Chen and Zhang (2010) estimated China's GHG emissions in 2007 using the IOA technique. They focused on CO_2, CH_4 and N_2O and found that GHG emissions represented 7,456.12 million tonnes CO_2-eq. By 63.39% of CO_2 emissions come related from the energy consumption, 22.31% does not relate to energy. There are 81.32% of total GHG emissions coming from electricity production, steam and hot water, iron melting, steel and non-ferrous metal products. In addition, China is also a net exporter of GHGs with up to 3,060.18 million tonnes CO_2-eq, or 41.04% coming directly from GHG emissions.

2.3.3 Social inventory database using Input-Output Analysis

After the introduction of social impact, there are a few studies on social database using the social footprint concept. European countries, USA, Australia, Japan, India and China have performed the S-LCA study at the company and product level. Table 2-3 shows the development of current studies on social footprint database. Key weak points of the database are that there is lack of availability of data due to databases not existing (mostly qualitative) and many social indicators are subjectively perceived and hard to evaluate. Benoıt–Norris et al. (2013) developed the social hotspot database using an IO table, which tried to cover all industry sectors and all social indicators.

Table 2-3. Overview of current studies on the social inventory databases.

Study	Database type	Classification of social issues	Industry coverage	Reference year
Benoıt–Norris et al. (2013)	IOA, National, Sectors	Direct, Indirect 22 social themes 134 social indicators	112 countries with 57 sectors	2004
Alsamawi et al. (2014)	IOA, Global	Direct, Indirect Employment and Income	187 countries with 85 sectors	2010
Simas et al. (2014)	IOA, Regions	Direct, Indirect 6 bad labor footprint	7 world regions 8 sectors	2007
Gómez–Paredes et al. (2015)	IOA, National	Direct, Indirect 6 labor issues: collective bargaining, forced labor, child labor, gender inequality, hazardous work, and social security	115 commodities	2011
This study	IOA, National, Asian Countries	Direct, Indirect Total employment Paid worker Vulnerable employment Wages Fatal accident in workplace Non-fatal accident in workplace	Thai IO (96 sectors) AIIO (76 sector with 10 countries)	2005

2.4 Characterization factor model for impact assessment of Social LCA

The impact assessment method in the Social LCA can be categorized into two groups: performance reference point and impact pathways methods. These categories can be described as follows.

Performance reference point methods evaluate the social impacts using the performance reference points based on the minimum performance levels of a recognized international standard, such as the ILO and the ISO 26000 guidelines. The colour coding, scoring and weighting system are applied to aggregate both qualitative and quantitative data into impact categories. These methods are suggested in the UNEP/SETAC Guidelines (Chhipi-Shrestha et al., 2015). Many S-LCA studies have used these methods to evaluate the social impacts in the S-LCA. Nevertheless, there are many techniques for impact assessment including checklists, scoring, and Social Hotspots Database (SHDB) methods. The SHDB method also applies a scoring technique, but these scores are prioritized based on a hotspot index. These methods are summarized in Table 2-4.

Table 2-4. Overview of existing studies applied the performance reference point methods for S-LCA.

Study	Stakeholder	Social category	Characterization method	Proposed method
Dreyer (2009)	Worker based on company level	4 subcategories: forced labour, child labour, discrimination, and freedom of association & collective bargaining	Multi-criteria model (Risk score: very high [0.9-1.0], high [0.6-0.9], high to medium [0.4-0.6], medium [0.2-0.4], low [0–0.2])	Scoring method
Franze and Ciroth (2011)	Worker, company, local community, society, consumers	19 subcategories & 21 indicators based on UNEP/SETAC guidelines	5 colour system: green to red (positive to very negative)	Checklist method
Ciroth and Franze (2011)	Worker, local community, society, value chain actors, consumers	30 subcategories & 88 indicators based on UNEP/SETAC guidelines	6 performance levels & score assigned: colour dark green [1], light green [2], bluish green [3], yellow [4], orange [5], red [6]	Scoring method
Benoıt- Norris et al. (2013)	Worker, local community, society, value chain actors	22 social themes; 134 indicators	-Social Hotspot Database (SHDB) System; -4 risk levels: low [0], medium [1], high [2], very high [3]); -calculated Social Hotspot Index (SHI); -Country/Sector level	Scoring based on the hotspot index using the SHDB system

Impact pathways methods appraise the social impacts of the product or service system based on the cause-effect chain relationship, including midpoint and/or endpoint impacts the same as the environmental LCA. The methods are applied depending on the quantitative indicators. These method are proposed by the UNEP/SETAC Guidelines and are summarized in Table 2-5.

Table 2-5. Overview of existing studies applied the Impact pathways methods for S-LCA.

Study	Stakeholder	Social category	Characterization method	Proposed method
Menikpura et al. (2012)	Local community	Human health (waste management)	DALY (from LCIA result)	DALY
Baumann et al. (2013)	Worker, consumers, society	Health impact (airbag case study)	YLL = (S_{airbag}/No of airbags produced per year) x Average life years saved per accident YLD = (P_{airbag}/No of airbags produced per year) x Duration of nonfatal accidents prevented x Severity of nonfatal (spinal cord) injury prevented	DALY
Scanlon et al. (2013)	Worker	Occupational health (1 industrial sector)	$YLL_n = \sum_{a=1}^{9}\sum_{s=1}^{2}\left(N_{a,s} * L_{a,s}\right)$ $YLD_n = \sum_{c=1}^{x}\sum_{a=1}^{5}\sum_{s=1}^{2}\left(I_{c,a,s} * W_{c,a} * D_{c,a,s}\right)$	WE-DALY

2.5 Summary

The novelty of the social inventory database in this thesis can be

1) The new social intensity database of Thailand including the total employment, paid worker, vulnerable employment, wages, fatal, and non-fatal occupational injuries using an input-output analysis (IOA) approach and social footprint concept for the 96 economic sectors based on Thailand's Input-Output table, and the 760 economic sectors of 10 countries based on the International Asian Input-Output table.

2) Modified characterization factors, human health impact reflecting the occupational health and safety issues in Thailand for the S-LCIA.

This study comprises of two parts: environmental and social footprint inventory database and modified social impact assessment method in term of DALY. The development of social footprint inventory using an IOA was attempted. The social impact assessment method in terms of DALY the occupational health and safety issues in Thailand was developed. Four case studies for investigation of the social footprint inventory and the social impact assessment were performed.

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Chapter 3. Development of Environmental Inventory Database using Thailand Input-Output Table

3.1 Introduction

The greenhouse effect and its potential to raise global temperatures has become an important international issue. Greenhouse gases (GHGs) consist of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 that are generated from various human activities. The most important GHG is CO_2 that accounts for a half of GHG contribution from human activities (IPCC, 2006). Since 1985, Thailand has achieved a high economic growth as the economic structure has significantly changed from being agriculturally oriented to an industrially oriented economy. The gross domestic product (GDP) annual growth rate in Thailand averaged 3.69% from 1994 until 2016, reaching an all-time high of 15.30% in the fourth quarter of 2012 and a record low of -12.50% in the second quarter of 1998 (NESDB, 2016). It should be noted that this growth has been at the expense of natural resource exploitation, by increases in fossil fuel use and deforestation ultimately leading to increase in the GHGs emitted to atmosphere. In addition, other air pollutant emissions (SO_2, NOx and particulate matter) are also increasing in Thailand due to the increasing demand for electricity and transportation fuels. The industrial growth, coupled with accelerated urbanization, can be held responsible for this increasing demand for electricity and transportation fuels.

Combustion of fuels that contained sulphur generated SO_2 that was emitted into the atmosphere. SO_2 is an important pollutant that contributes to acid deposition and leads to potential changes arising in the quality of soil and water. The endpoint impacts of acid deposition can be effects on aquatic ecosystems and damage to vegetation. Acidification can also result in damage to construction. In addition, SO_2 also formulate to form the particulate aerosols in the atmosphere. SO_2 emitted from fuel combustion mainly depends on the sulfur content of the fuel and, unlike CO_2 and NOx emissions, that depends on the operating conditions in the combustion process. The NOx generation is dependent on the excess air in the combustion system and the flame temperature. NOx are an important family of air polluting chemical compounds, but they also react in the atmosphere to generate ozone (O_3) and acid rain. Automobiles and other mobile sources generate accounting for a half of the NOx that is emitted. Boilers in the power plants are stationary sources that contribute about 40% of the NOx emissions. In addition, NOx emissions are also added from industrial boilers, incinerators, iron and steel manufacturing, cement production, glass production, petroleum refineries, and nitric acid production. The natural sources of NOx include forest fires, grass fires, and agricultural residues burning (WHO, 2006).

Particulate matter (PM) is a pervasive air pollutant, comprising of a mixture of solid and liquid particles suspended in the air. The common indicators of PM that are relevant to health impacts refer to the mass concentration of particles with a diameter of less than 10 µm (PM10) and of particles with a diameter of less than 2.5 µm (PM2.5). Particles are classified as the primary PM and secondary particles, depending on the compounds and processes related to its formation. Primary PM is a particle form that is produced at the emissions source, such as the smoke at the stack of power plant, etc. Secondary PM is produced from chemical and physical reactions relating to the different precursor gases, such as SO_2 and NOx (WHO, 2006).

To understand the embodied impacts of each industrial sector on the GHG emissions and other air pollutants, this study developed an environmental inventory database based on an input–output analysis (IOA) regarding Thailand's 2005 economic IO tables (THIO). The environmental issues included the GHG emissions (CO_2, CH_4, and N_2O), and other air pollutants (SO_2, NOx, and PM).

3.2 Methodology

3.2.1 Environmental inventory database development based on IO model

This study uses the 2005 IO table of Thailand which consists of 180×180 sectors in the analyses. The calculation steps for the environmental intensity database are presented in Figure 3-1.

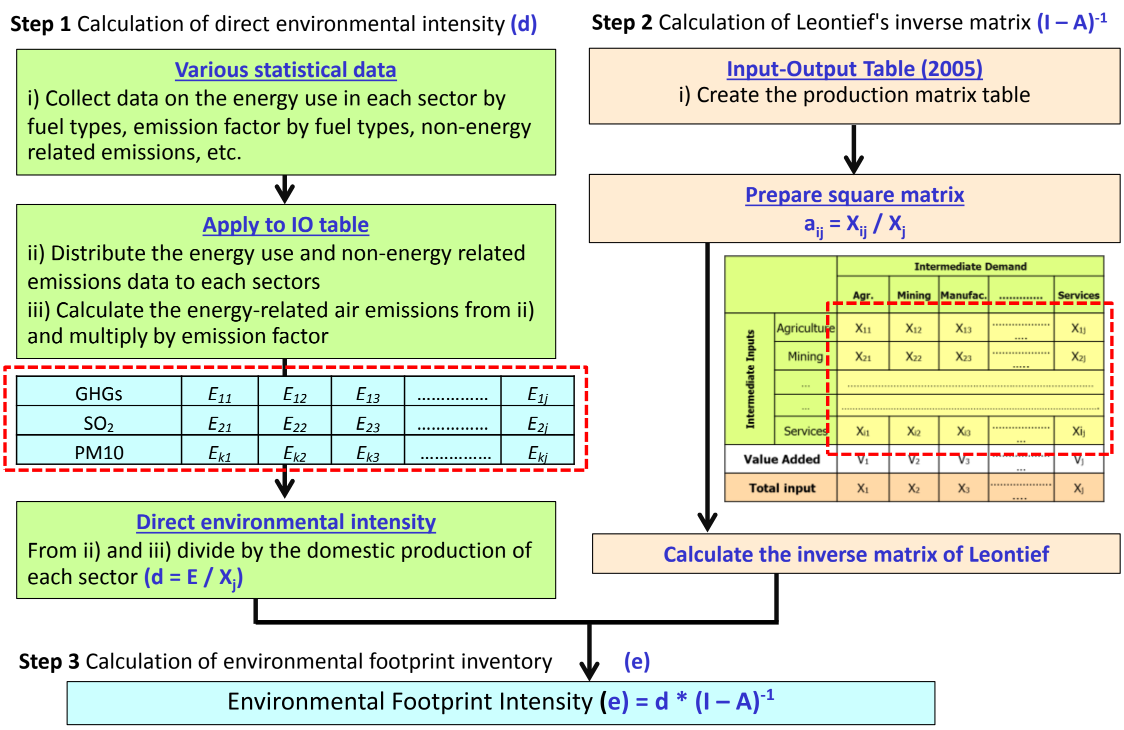

Figure 3-1. Calculation steps of the environmental intensity database using the THIO table.

3.2.1.1 Assumptions and limitations

The applying IOA in this study involves some assumptions summarized in the following:

- Constant technological coefficients: the amount of input necessary to produce one unit of output is assumed to be constant in the short term, regardless to price effects, changes in technology or economies of scale.
- Linear production functions: the IOA assumes that if the output level of industry changes, the input requirements will change proportionally.
- It is assumed that each economic sector produces and sells one and only one homogeneous good.
- There are no resource constraints. Supply is assumed infinite and perfectly elastic.
- Local resources are efficiently employed. There is no underemployment of resources.
- IO tables describe an economy in a specific period; they do not highlight the trend of the economic interrelationship in a long time.
- This study was considered effect within domestic and import from the rest of the world (RoW). Imports from the RoW implicitly assumes that the same production characteristics and technologies as comparable products made in Thailand. It is also assumed in this model that RoW have the same technology, and although there are the difference between the domestic or import commodity price. We assumed that other countries have the same technology and direct environmental coefficients as the country analyzed. In this case, the environmental impact embodied in imports can be defined as the foreign environmental impacts represent the actual impact generated by Thailand.

3.2.1.2 Calculation of direct environmental intensity

The modified IO model adds a row for environmental aspects to show the environmental issues involved in production processes, thus quantifying the environmental footprint for the final demand in different sectors. The environmental footprint matrix (d) is an extension of the direct input coefficient matrix for environmental issues. Where d is a $k \times j$ matrix, E_{kj} is environmental issue k (e.g., CO_2, CH_4, N_2O, SO_2, NOx, and PM10) per monetary output of sector j. The matrix d is defined as:

$$d = d_{kj} = E_{kj} / X_j \qquad (k = 1,\ldots, m;\ j = 1, \ldots, n) \qquad (3\text{-}1)$$

This study analyzes six different environmental inventories, the dimensions of the environmental matrix are d (6 × 180). Elements in the environmental matrix reflect the impacts per sectoral output, e.g., 50 kg CO_2 per 1000 Thai Baht for the paddy rice sector.

3.2.1.3 Calculation of Leontief's inverse matrix

The direct input coefficient is the ratio of the intermediate demand inputs (sales from sector i to sector j) (X_{ij}) and the total output of sector j (X_j). The set of input coefficients of all economic sectors is expressed in the square matrix A (n x n), which is called the direct input coefficient matrix. n is the number of sectors or the dimension of the economic system. The matrix A defined as:

$$A = a_{ij} = X_{ij} / X_j \qquad (i, j = 1, \dots, n) \tag{3-2}$$

so that in matrix notation equation (3-2) becomes

$$x = Ax + Y \tag{3-3}$$

Solving for x yields

$$x = (I - A)^{-1} Y \tag{3-4}$$

where I is the identity matrix (n x n), Y is the vector of final demand and $(I - A)^{-1}$ is called the Leontief inverse matrix.

This study developed the input coefficient matrix based on the 2005 economic IO table of Thailand with 180 × 180 economic sectors.

3.2.1.4 Calculation of total environmental impacts

The total environmental impact vector (f) of goods or services *versus* a given amount for economic demand is:

$$f = dx = d\ (I - A)^{-1}\ Y \tag{1-5}$$

where A is the direct input coefficient matrix (calculated by dividing the industry-by-industry direct requirements of sectoral inputs by the sectoral output); I is the identity matrix; d is the environmental footprint matrix; and Y is the final demand vector. $(I - A)^{-1}$ is the matrix of input–output multipliers and shows the total effects (direct and indirect) on sectoral production caused by unitary changes in the final demand of sectors.

3.2.2 Data processing

This study developed the environmental inventory database based on the IO model using Thailand 180-sector input–output table in 2005 (NESDB, 2014). The model represents a picture of the Thai economy and environmental impact in 2005. Before applying IOA, the collected data must be harmonized with the compatible IO table form. This can be done by following tables are consistent with the classification of IO table and specification of each industrial sector. The environmental inventory established in this study included CO_2, CH_4, N_2O, SO_2, NOx, and PM10. The summary of environmental indicators used in this study is presented in Table 3-1.

Table 3-1. Summary of environmental indicators used in the study.

Measure	Indicators	Unit	Definition	Data Source	Data Year
Greenhouse gases (GHGs)	Total GHGs emissions	kg CO_2 eq.	Total GHGs (CO_2, CH4 and N_2O) generated for the production of goods and services.	DEDE (2005a) DEDE (2005b) DEDE (2005c) IPCC (2006) OAE (2009)	2005
Sulphur dioxide	SO_2	kg SO_2	Total SO_2 generated for the production of goods and services.	DEDE (2005a) DEDE (2005b) DEDE (2005c) EEA (2013) OAE (2009)	2005
Nitrogen oxides	NOx	kg NOx	Total NOx generated for the production of goods and services.	DEDE (2005a) DEDE (2005b) DEDE (2005c) EEA (2013) OAE (2009)	2005
Particulate matter	PM10	kg PM10	Total PM10 generated for the production of goods and services.	DEDE (2005a) DEDE (2005b) DEDE (2005c) EEA (2013) OAE (2009)	2005

The data mapping steps of the environmental inventory data into the environmentally extended input-output model are presented in Figure 3-2.

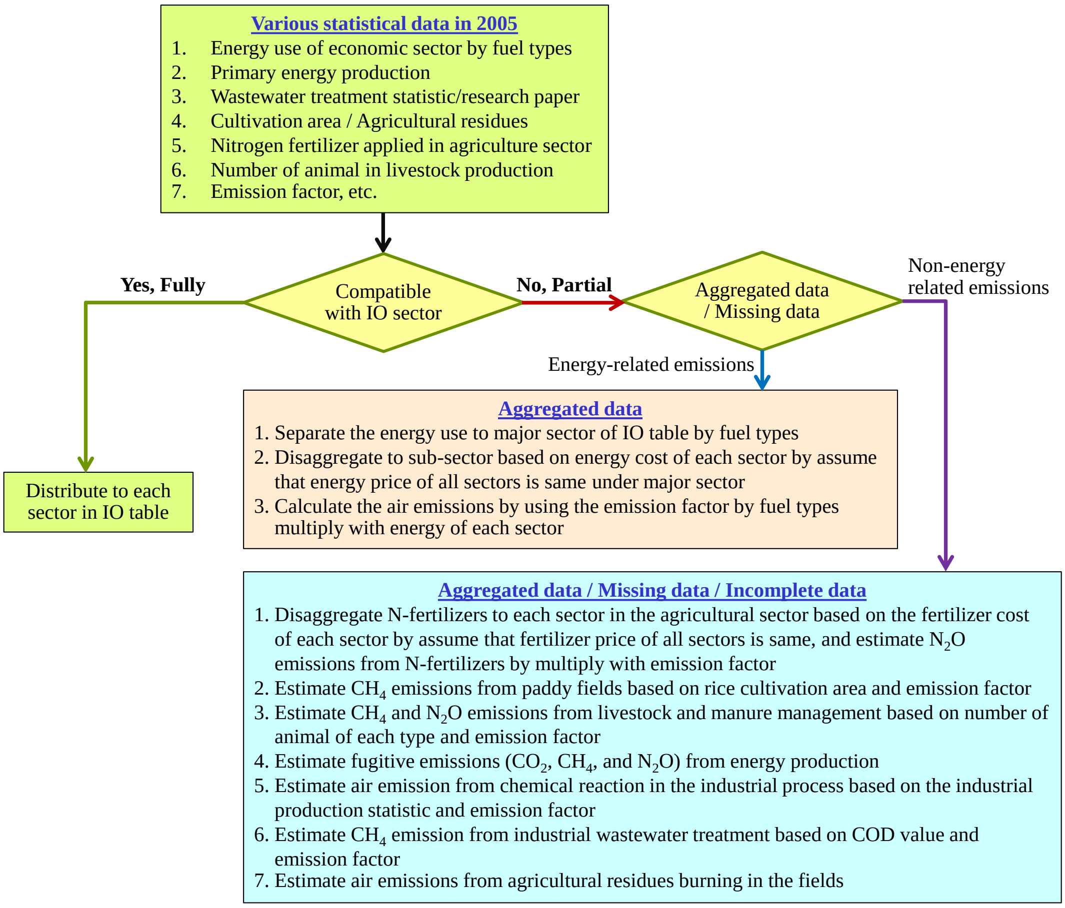

Figure 3-2. Data mapping steps of the environmental inventory data into the THIO table.

Greenhouses (GHGs) emissions

GHGs emissions (CO_2, CH_4 and N_2O) from energy use in each industrial sector were estimated from the energy combustion and chemical reactions (flue gas desulfurization) in the energy transformation processes, based on the 2006 IPCC guidelines. To estimate the GHGs emissions from the industrial process such as cement, lime, pulp and paper, iron and steel, petrochemical, food and beverage industries were calculated based on the IPCC guidelines. Emissions from methane and other gases such N_2O, from the enteric fermentation, iron and steel, rice cultivation, burning of crop residues and agriculture soils was estimated based on the 2006 IPCC guidelines (IPCC, 2006).

SO_2, NOx, and particulate matter emissions

SO_2 emitted into the atmosphere are an important environmental aspect because they react with other air pollutants to produce sulfate particles, which are complements of fine particulate matter (PM2.5). Inhalation exposure to PM2.5 has been linked with various cardiovascular and respiratory health effects (Pražnikar and Pražnikar, 2012). SO_2 and NOx contributes to acidic deposition. They also can damage vegetation caused the foliar injury increase, plant growth and yield decrease, and variety of plant species decrease (US EPA, 2008).

Air pollutants (SO_2, NOx and PM) from energy use in each industry sector were calculated from the energy combustion process based on the 2006 IPCC guidelines and the EEA guidebooks. The emission factors are provided for the estimation of these pollutants, with the exception of SO_2.

To estimate the SO_2 emissions the following equation (3-6) is used, which assumes that 100% of sulfur contained in fuel is conversed to SO_2:

$$SO_2 \text{ emission (kg/year)} = \text{fuel use (kg/year)} \times S \times 2 \quad (3\text{-}6)$$

where, fuel use is the feed rate of fuel to the combustion system in kg/year and S is the fraction of sulfur (as elemental S) in the fuel based on mass basis.

3.2.2.1 Agriculture sector

To estimate the air pollutants from fuel combustion

The agriculture sector is included in all 29 economic sectors from 001 to 029. To evaluate the energy use in the agriculture sector refer to the data from the Thailand energy report in 2005 by Department of Alternative Energy Development and Energy Conservation (DEDE; 2005a, 2005b, 2005c). It is found that the major Thai agriculture are the energy use in the form of petroleum fuel as shown in Table 3-2.

Table 3-2. Fuel use in the agriculture sector by fuel types.

Fuel types	Amount of energy use	
	Million liter/year	TJ/year
Liquefied petroleum gas	4	106.48
Gasoline	68	2140.64
Diesel	3631	132241.02
Fuel oil	4	159.08

Source: DEDE (2005a, 2005b, 2005c)

Based on the assumptions that a price per unit of energy of all agriculture sectors is constant, the energy use of each sector is shown in Table 3-3. To estimate the amount of air pollutants emitted from burning fossil fuels in agriculture, the calculation uses the emission factor from the 2006 IPCC guidelines and the EEA air pollutant emission inventory guidebook 2013. Air emissions from fossil fuel combustion will be estimated as follow:

$$\text{Emission (kg/year)} = \sum (\text{energy use}_i \text{ (TJ/year)} \times EF_i \text{ (kg gas/TJ)}) \quad (3\text{-}7)$$

where EF_i represents the emissions factor of each energy type 'i' (kg gas/TJ), and subscript 'i' is the energy type such as LPG, gasoline, diesel, and fuel oil.

Table 3-3. Fuel used by sub-sector in the agriculture sector in the year 2005.

IO code	Sector name	Diesel (million liter)	Fuel oil (million liter)	Gasoline (million liter)	LPG (million liter)
001	Paddy	361.66	-	6.83	-
002	Maize	18.05	-	0.34	-
003	Other cereals	0.18	-	0.00	-
004	Cassava	7.83	-	0.15	-
005	Other root crops	0.66	-	0.01	-
006	Beans and nuts	23.82	-	0.45	-
007	Vegetable	376.50	-	7.11	2.19
008	Fruits	306.14	-	5.78	-
009	Sugar cane	46.98	-	0.89	-
010	Coconut	0.09	-	0.00	-
011	Oil Palm	67.00	-	1.27	-
012	Kenaf and Jute	0.72	-	0.01	-
013	Other crops for textile and matting	0.33	-	0.01	-
014	Tobacco	9.07	-	0.17	-
015	Coffee and Tea	9.48	-	0.18	-
016	Rubber	11.61	-	0.22	-
017	Other Agricultural Products	26.51	-	0.50	0.65
018	Cattle and Buffalo	44.75	0.08	0.85	-
019	Swine	25.39	0.05	0.48	-
020	Other Livestock	0.17	0.00	0.00	-
021	Poultry	14.48	0.03	0.27	0.21
022	Poultry Products	69.17	0.13	1.31	-
023	Silk Worm	0.06	-	0.00	-
024	Agricultural services	462.03	0.85	8.73	-
025	Logging	6.33	0.01	0.12	-
026	Charcoal and Firewood	1.15	0.00	0.02	-
027	Other Forestry Products	2.10	0.00	0.04	-
028	Ocean and Coastal Fishing	1,630.42	3.01	30.81	0.52
029	Inland Fishing	107.97	0.20	2.04	-
	Total	3,630.67	4.36	68.60	3.57

LPG, gasoline, diesel and fuel oil are the fuels used in equipment and agricultural machinery. Diesel will partly be used to fuel in the mobile equipment/machinery, such as tractors and plows. The emissions factor of each fuel used in the calculation is shown in Table 3-4.

Table 3-4. Emission factor of the air pollutants from burning fossil fuels in the agriculture by fuel types (unit: g/GJ).

Air pollutants	LPG	Gasoline	Diesel	Fuel oil
CO_2	63100	69300	74100	77400
CH_4	5	10	10	10
N_2O	0.1	0.6	0.6	0.6
SO_2	5	15	10	560
NOx	20	20	20	20
PM10	0.78	20	20	20

Sources: IPCC (2006); EEA (2013)

From the data on the amount of fuel use and the emission factor can be calculated for the air pollutants caused by the combustion in agriculture machinery is given in Table A-1 (in the appendix A).

To estimate the non-energy related air emissions

Livestock sector

Methane (CH_4) is a primary GHG emission from livestock that is derived from the feed digestive processes, mainly in ruminants and from animal manure. Enteric fermentation is herbivores generates methane as a by-product of the digestive process. The ruminant animals (cattle and buffalo) are the largest source of methane production.

CH_4 emitted from the enteric fermentation and animal manure (included N_2O emission) was calculated based on the 2006 IPCC guidelines (IPCC, 2006). CH_4 generation from the enteric fermentation process will be estimated as follow:

$$E_f = \sum (\text{animal population}_n \times EF_{fn}) \quad (3\text{-}8)$$

where E_f represents the quantity of CH_4 emission (kg/year), EF_{fn} represents the emissions factor of the enteric fermentation for animal ‘n’ (kg/head), and animal population is the average population of animal type ‘n’ (head/year).

Rice cultivation

According to the 2006 IPCC guidelines, CH_4 generation from paddy fields can be calculated using the equation (3-9):

$$F = EF_{ijk} \text{ x } A_{ijk} \text{ x } T_{ijk} \quad (3\text{-}9)$$

where EF is the emission rate of methane (kg/has/day), A is a paddy area (ha), and T is a seasonal cropping period (day). Subscripts ‘i’, ‘j’, and ‘k’ represent water regimes (irrigated, rainfed, deep water and dry), fertilizer applications and cropping periods (depending on rice cultivars), respectively.

N_2O emissions from soil

The emissions of N_2O depend on the amount of chemical nitrogen fertilizers applied in agricultural soils as well as the organic fertilizers. They are emitted through fractions volatized from cultivated soils and from also generation of N_2O from leached groundwater. Based on the 2006 IPCC guidelines (IPCC, 2006), N_2O emission from the agricultural soils can be calculated as follow:

$$N_2O_{direct} = (F_{SN} + F_{AW} + F_{BN} + F_{CR}) \times EF_1 \quad (3\text{-}10)$$

where EF_1 = emission factor for direct soil emissions (0.0125 kg N_2O -N/kg-N_{input})
F_{SN} = synthetic nitrogen fertilizer applied in cultivation (kg-N/year)
F_{AW} = animal manure nitrogen used as fertilizer (kg-N/year)
F_{BN} = N fixed by N-fixing crops in country (kg-N/year)
F_{CR} = N in crops residues returned to soil in country (kg-N/year)

Air emission from agricultural burning in the fields

The burning of agricultural residues in the fields take into account in this study. Burning of biomass also releases the CO_2 and non- CO_2 emissions. However, CO_2 emissions from biomass combustion were not excluded in this analysis due to carbon neutral rule, CO_2 emitted from combusted biomass comes from CO_2 uptake during the plant growth. For non-CO_2 emissions (CH_4, N_2O, NOx, SO_2, PM10), estimate based on the amount of agricultural residues in the fields, fraction of combustion area in the fields, and emission factor from the IPCC guidelines 2006 and the EEA guidebook 2013.

3.2.2.2 Non-agriculture sector

To estimate the air pollutants from fuel combustion

The total energy use for each energy type of each industrial sector in Thailand are gathered from the Thailand Energy Report in 2005 (DEDE; 2005a, 2005b, 2005c). However, the published sector based data are limited relevant to the whole figure of energy use in Thailand, e.g., manufacturing sectors are not classified into a sub-sector. In the case of aggregated data, this study allocated the quantity of energy use for each sub-sector based on the energy cost of each sector. All data referred to information from the year 2005. This study will evaluated over 180 industrial sectors.

Fossil fuel combustion is the burning of coal, oil, or natural gas used to generate energy. Coal contains the high carbon content per unit of energy, whereas natural gas contains the least. Common sources of fossil fuel consumption are various transport, steam generation for industrial processes, heating in residential and commercial buildings, and power generation. Fossil fuel combustion may also emit unburned hydrocarbons, methane, and carbon monoxide. The calculation of CO_2 as well as non-CO_2 emissions can be done based on the 2006 IPCC guidelines and the EEA guidebook 2013.

Fossil fuel use is converted from physical unit to common energy units by using local conversion factors. This study converts the specific unit to tera-joules (TJ). CO_2 emission from fossil fuel combustion can be estimated as follows:

$$CO_2 \text{ emission} = \sum_i (\text{fuel use}_i \text{ (TJ/year) x emission factor}_i \text{ (kg } CO_2\text{/TJ))} \quad (3\text{-}11)$$

where subscript ‘i’ represent the fuel type.

For non-CO_2 such as CH_4, N_2O, etc., the calculation can be applied the equation as follows:

$$\text{Emission} = \sum_i (\text{fuel use}_i \text{ (TJ/year) x emission factor}_i \text{ (kg gas/TJ))} \quad (3\text{-}12)$$

Biomass burning is the burning of organic materials such as wood and agricultural residues for energy production. Burning of biomass also releases the CO_2 and non- CO_2 emissions. However, CO_2 emissions from biomass combustion were not excluded in this study due to carbon neutral rule, CO_2 emitted from combusted biomass comes from CO_2 uptake during the plant growth.

For non-CO_2 emissions from combusted biomass, the equation as in case of fossil fuel can be applied.

The emissions factor of each fuel used in the estimation is presented in the appendix (Table A-2).

Fugitive emission from energy production

Fugitive emissions from various activities of the energy production are not related to fuel combustion for heat production. These emission happen during the solid fuel production process during mining, post-mining, and post-combustion of coal activities. For crude oil and natural gas production, they are generated through leakages in the process of extraction, storage, and transmission to end-users. Consequently, leakage of any gas components that have a low molecular weight, such as CH_4 and volatile organic carbon (VOC), are more possibly to arise.

In the lignite-fired and coal-fired power plants, the large amount of coal are pulverized to fine dust and then burned at very high temperatures. It releases the various types of air pollutant, such as CO_2, CO, SO_2, NOx, lead, arsenic, nickel, cadmium and particulate matter.

Coal mining activities

Based on the 2006 IPCC guidelines provide, the CH_4 emissions factor for coal mining activities, CH_4 emission can be estimated by using equation (3-13) to (3-14) as follows:

CH_4 emissions (1000 tonne/year) = CH_4 Emission Factor (m^3/tonne) x Surface Coal Production (tonne/year) x Conversion Factor (3-13)

where, average CH_4 emission factor = 1.2 m^3/tonne.

Density of CH_4 and converted volume of CH_4 to the mass of CH_4 at 20°C and 1 atmosphere pressure is 0.67 x 10^{-3} tonne/m^3.

Post-mining activities

CH_4 emissions (1000 tonne/year) = CH_4 Emission Factor (m^3/tonne) x Surface Coal Production (tonne/year) x Conversion Factor (3-14)

where, average CH_4 emission factor = 0.1 m^3/tonne.

Density of CH_4 and converted volume of CH_4 to the mass of CH_4 at 20°C and 1 atmosphere pressure is 0.67 x 10^{-3} tonne/m^3.

Oil production

CO_2 emissions (1000 tonne/year) = $\sum_i$ (CO_2 Emission Factor (1000 tonne/m^3 heavy oil production) x Heavy Oil Production (m^3 /year)) (3-15)

CH_4 emissions (1000 tonne/year) = $\sum_i$ (CH_4 Emission Factor (1000 tonne/m^3 heavy oil production) x Heavy Oil Production (m^3 /year)) (3-16)

N_2O emissions (1000 tonne/year) = $\sum_i$ (N_2O Emission Factor (1000 tonne/m^3 heavy oil production) x Heavy Oil Production (m^3 /year)) (3-17)

where subscript 'i' represents the oil production activities such as well drilling, well testing and well servicing.

Table 3-5. Emission factor of the air pollutants from oil production activities.

Activities	CO_2	CH_4	N_2O	Unit
Well drilling	9.0E-07	3.0E-07	0	1000 tonne/m^3 heavy oil production
Well testing	8.0E-05	4.5E-07	5.8E-10	
Well servicing	1.7E-08	9.6E-07	0	
Total	8.0E-05	1.7E-06	5.8E-10	

Source: IPCC (2006)

Natural gas production

CO_2emissions (1000 tonne/year) = $\sum_i$ (CO_2 Emission Factor (1000 tonne/m^3 gas production) x Gas Production (m^3 /year)) (3-18)

CH_4 emissions (1000 tonne/year) = $\sum_i$ (CH_4 Emission Factor (1000 tonne/m^3 gas production) x Gas Production (m^3 /year)) (3-19)

N_2O emissions (1000 tonne/year) = $\sum_i$ (N_2O Emission Factor (1000 tonne/m^3 gas production) x Gas Production (m^3 /year)) (3-20)

where subscript 'i' represents the oil production activities such as fugitives and gas flaring.

Table 3-6. Emission factor of the air pollutants created from natural gas production activities.

Activities	CO_2	CH_4	N_2O	Unit
Fugitives	9.7E-11	1.2E-08	0	1000 tonne/m^3 gas production
Gas flaring	1.4E-09	8.8E-13	2.5E-14	
Total	1.5E-09	1.2E-08	2.5E-14	

Source: IPCC (2006)

Estimating the air emissions from industrial processes

Air emissions from industrial processes were generated from non-energy related activities but through the production processes, such as calcination process. Types of air emitted depend on the nature of the manufacturing processes such as chemical reactions, conversion efficiency. The inventory presented in Table 3-7 explains the emissions from the following industrial processes: cement production, lime manufacturing, glass production, iron and steel production, and caprolactam production.

Table 3-7. Emission factor of the air pollutants from industrial process.

Industry	Emission factor	Unit
Cement production	0.52	tonnes CO_2/ tonne clinker
Lime production	0.75	tonnes CO_2/ tonne lime produced
Glass production	0.20	tonnes CO_2/ tonne glass
Iron and steel production	0.08	tonne CO_2/ tonne of steel produced
Caprolactam production	9.00	kg N_2O /tonne caprolactam

Source: EEA (2013)

Estimating the GHGs emission from wastewater treatment processes

Assessment of CH_4 generation potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industrial sector to treat their wastewater in anaerobic systems. Based on these criteria, main industrial wastewater sources with high CH_4 generation potential can be identified as the following: pulp and paper production, meat and poultry processing, alcohol and beer production, starch production, dairy products, vegetable oil, fruits and vegetables, etc. The general equation to estimate CH_4 emissions from industrial wastewater is as follows:

$$CH_4 \text{ emissions (kg/year)} = \sum [(TOW - S) \times B_o \times MCF - R] \quad (3\text{-}21)$$

where TOW = total organic degradable material in wastewater (kg COD/year)

S = organic component removed as sludge (kg COD/year)

B_o = maximum CH_4 producing capacity (0.25 kg CH_4/kg COD)

MCF = methane correction factor

R = amount of CH_4 recovered to energy source (kg CH_4/year)

3.3 Results

3.3.1 Greenhouse gases (GHGs)

3.3.1.1 GHGs intensity

The GHGs intensity, expressed in terms of tonne CO_2-eq per 1000 US$, output of 180 industrial sectors in Thailand in the year 2005 are presented in Figure 3-3. The total emissions consists of the direct emissions the producing industry, the indirect emissions of domestic intermediate inputs, and indirect emissions of imports. The emission intensities of imported products are assumed to be the same as the corresponding products of the domestic sectors. Based on 1000 US$ output, an average GHGs intensity of Thai industry is 2.10 tonne CO_2-eq with the standard deviation is 2.06 tonne CO_2-eq. The largest GHGs intensity is in the cement sector, accounting for 16.08 tonne CO_2-eq that is more than double the average value about 7.7 times. The highest intensity is in the cement sector due to consumption of large amounts of fossil fuels especially as coal is used in the production processes. The next was the cattle and buffalo sector (14.88 tonne CO_2-eq) followed by the tapioca milling (9.88 tonne CO_2-eq), paddy rice production (8.53 tonne CO_2-eq), electricity (7.14 tonne CO_2-eq), rice milling (7.01 tonne CO_2-eq), monosodium glutamate (6.49 tonne CO_2-eq), road freight transport (6.15 tonne CO_2-eq), non-ferrous metal (5.27 tonne CO_2-eq), road passenger transport (5.23 tonne CO_2-eq), and palm oil (4.82 tonne CO_2-eq). Due to the fact that these sectors are energy intensive (cement, electricity, road passenger transport, monosodium glutamate, and non-ferrous metal sector) or they produce methane emissions from the process (such as rice cultivation, cattle and buffalo, tapioca milling, and palm oil milling sector).

Agriculture and food–related sectors show up in eight categories out of the top 20: paddy, cattle and buffalo, swine, tapioca milling, rice milling, monosodium glutamate, coconut and palm oil, and flour and other grain milling. The majority of these sectors are generating the methane emissions from waste treatment (cattle and buffalo, swine, tapioca milling, coconut and palm oil, and flour and other grain milling), and rice cultivation stage (rice milling). The transportation sectors presented four categories out of the top 20 consisting of the road passenger transport, road freight transport, coastal and inland water, and ocean transport. The GHG intensity of the cattle and buffalo sector is higher than other sector in agriculture due to it’s low economic value.

The direct intensity of 22 sectors out of 180 sectors are higher than the indirect intensity. More evidently in 8 of the sectors (cement, paddy, electricity, cattle and buffalo, agricultural services, road passenger transport, coastal and inland water transport, and road freight transport sectors), the direct intensity accounts for 80% of the total emissions. In addition, for all transportation modes the direct intensity is higher than indirect emissions.

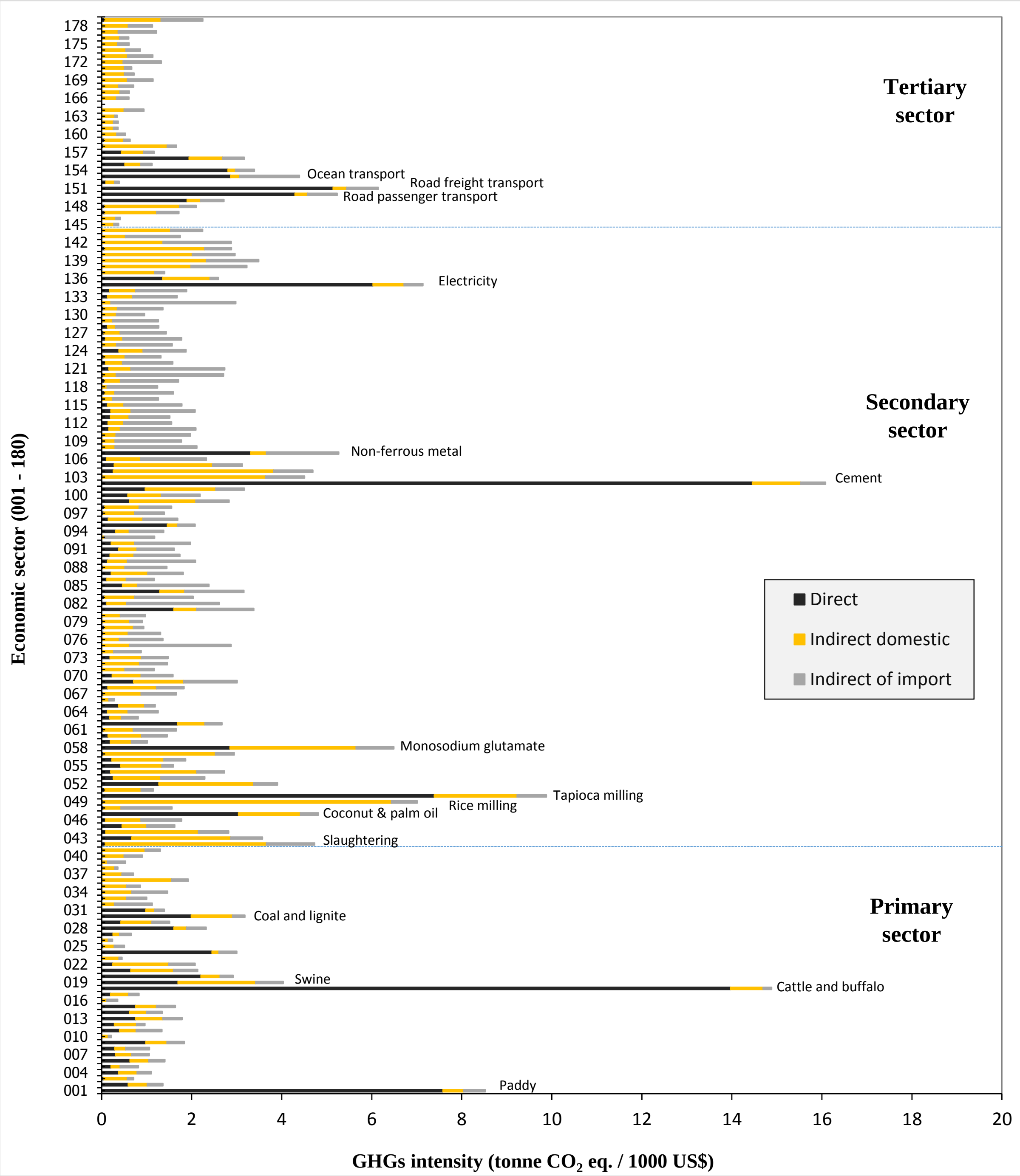

Figure 3-3. GHGs intensity of Thailand by economic sector using the 2005 THIO table.

The total GHGs intensity can be further divided by the emission type. Figure 3-4 shows the embodied GHGs intensities by emission type: carbon dioxide, methane, and nitrous oxide, for all sectors. The contribution of CH_4 emission intensities are especially high in the cattle and buffalo, paddy, swine, slaughtering, tapioca milling, rice milling, coconut and palm oil, flour and other grain milling, coal and lignite, monosodium glutamate, noodles and similar products, pulp and paper, rubber sheet and block rubber, and distilling blending spirits sectors. Total GHGs intensities of many industries are dominated by the embodied CO_2 emission, except for the previous mentioned sectors. The shares of N_2O emission intensities are high in the cattle and buffalo sector and sector 20 (other livestock).

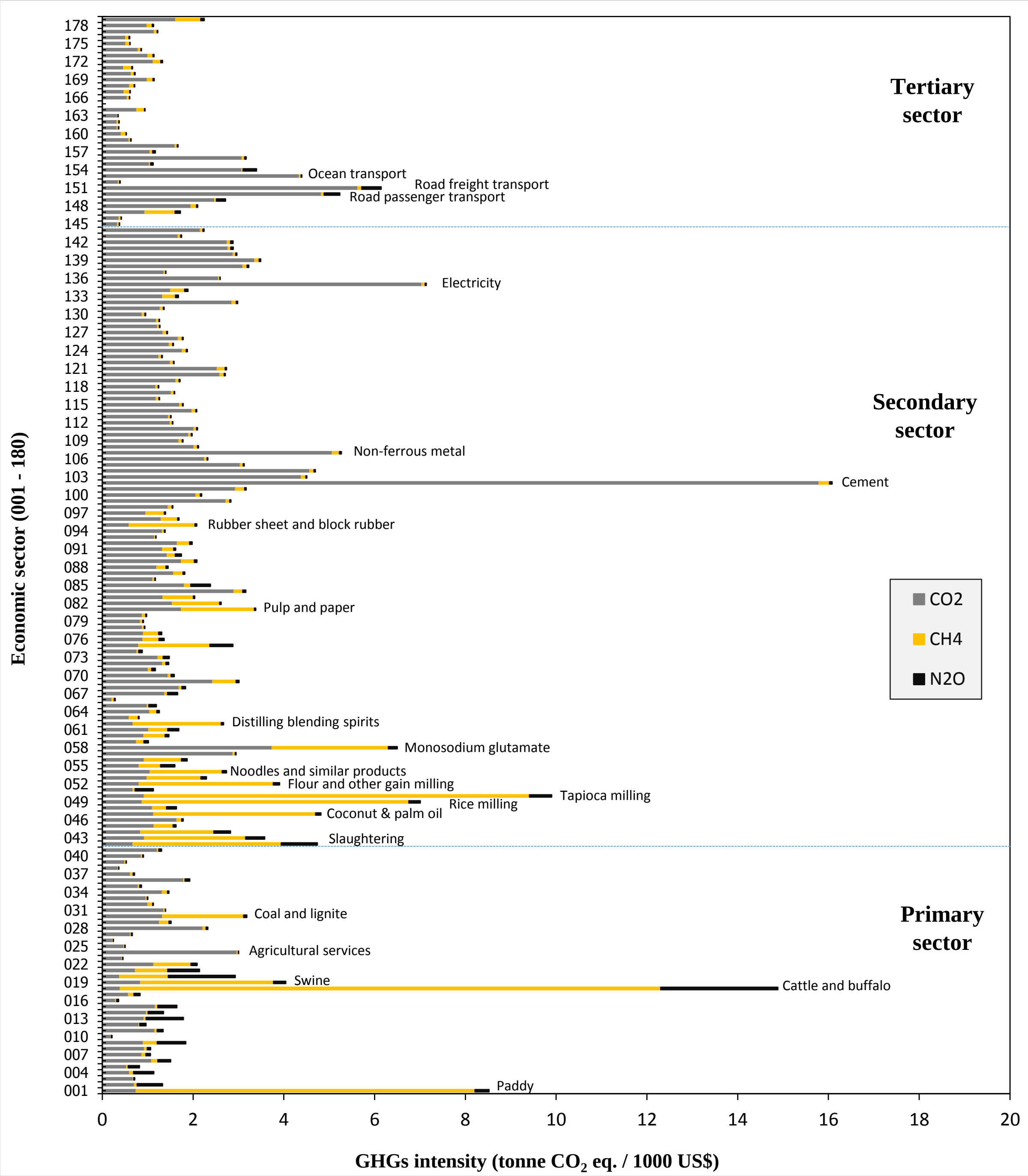

Figure 3-4. Emission component of the embodied GHGs intensity by economic sector.

4.3.1.2 GHGs footprint

The results of the total embodied GHG emissions or GHG footprints of Thailand based on domestic consumption in the year 2005 are shown in Figure 3-5. The total GHG footprints accounted for 341 million tonnes CO_2-eq or 5.24 tonnes CO_2-eq per capita. When comparing the GHG footprint per capita of this study with a similar study in Thailand (UNFCCC, 2014), they reported GHG emissions of 5.40 tonnes CO_2 eq. per capita. The result of this study was similar to the previous studied in Thailand. Compared to the GHGs intensities, the ranking changes and the most important GHG intensive sector becomes the electricity generation sector (84.92 million tonnes CO_2-eq.), followed by cement (33.36 million tonnes CO_2-eq.), paddy (26.33 million tonnes CO_2-eq.), crude oil and natural gas (24.98 million tonnes CO_2-eq.), non-ferrous metal (21.96 million tonnes CO_2-eq.), road passenger transport (20.16 million tonnes CO_2-eq.), cattle and buffalo (15.23 million tonnes CO_2-eq.), basic chemical (15.16 million tonnes CO_2-eq.), road freight transport (14.64 million tonnes CO_2-eq.), pulp and paper (7.89 million tonnes CO_2-eq.), and gas separation and distribution sector (7.11 million tonnes CO_2-eq.).

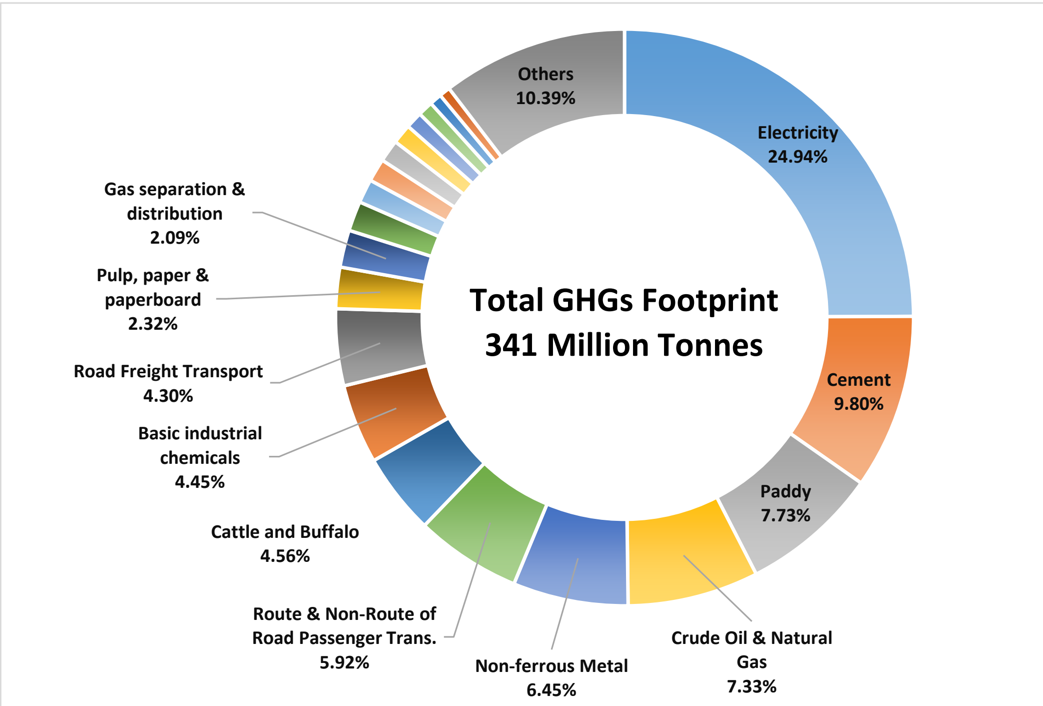

Figure 3-5. GHGs footprint of Thailand based on domestic consumption in 2005.

3.3.2 Sulfur dioxide (SO_2)

3.3.2.1 Sulfur dioxide intensity

Figure 3-6 shows the sulfur dioxide intensity by sector expressed in terms of kg SO_2 per 1000 US$ output. The total SO_2 intensity comprises of the direct emissions, indirect emissions from domestic supply chain, and the indirect emissions of imports. Based on 1000 US$ output, an average SO_2 intensity of Thai industry is 3.76 kg SO_2 with the standard deviation is 4.61 kg SO_2. The largest SO_2 intensity is in the ocean transport sector, accounting for 45.60 kg SO_2, around 12 times higher than the average value. The highest SO_2 intensity in the ocean transport sector is due to using the large amount of fuel oil with 2% sulfur content by weight. The top 10 ranking in sulfur dioxide intensity are the ocean transport (45.60), cement (29.29), monosodium glutamate (17.44), non-ferrous metal (17.04), basic industrial chemicals (11.48), textile bleaching and finishing (11.39), other petroleum products (10.62), electricity (10.12), jewelry and related articles (9.23), and iron and steel sector (9.19). These industrial sectors have higher SO_2 intensities due to the coal and fuel oil combustion in the processes.

If we considered the indirect effect of import, the results showed that the textile and garment sectors (sector 67–77), the chemical products (sector 84–97), and the metal products, electronics, and machinery (sector 108–131) are responsible for more than haft of total SO_2 emissions in the import sector.

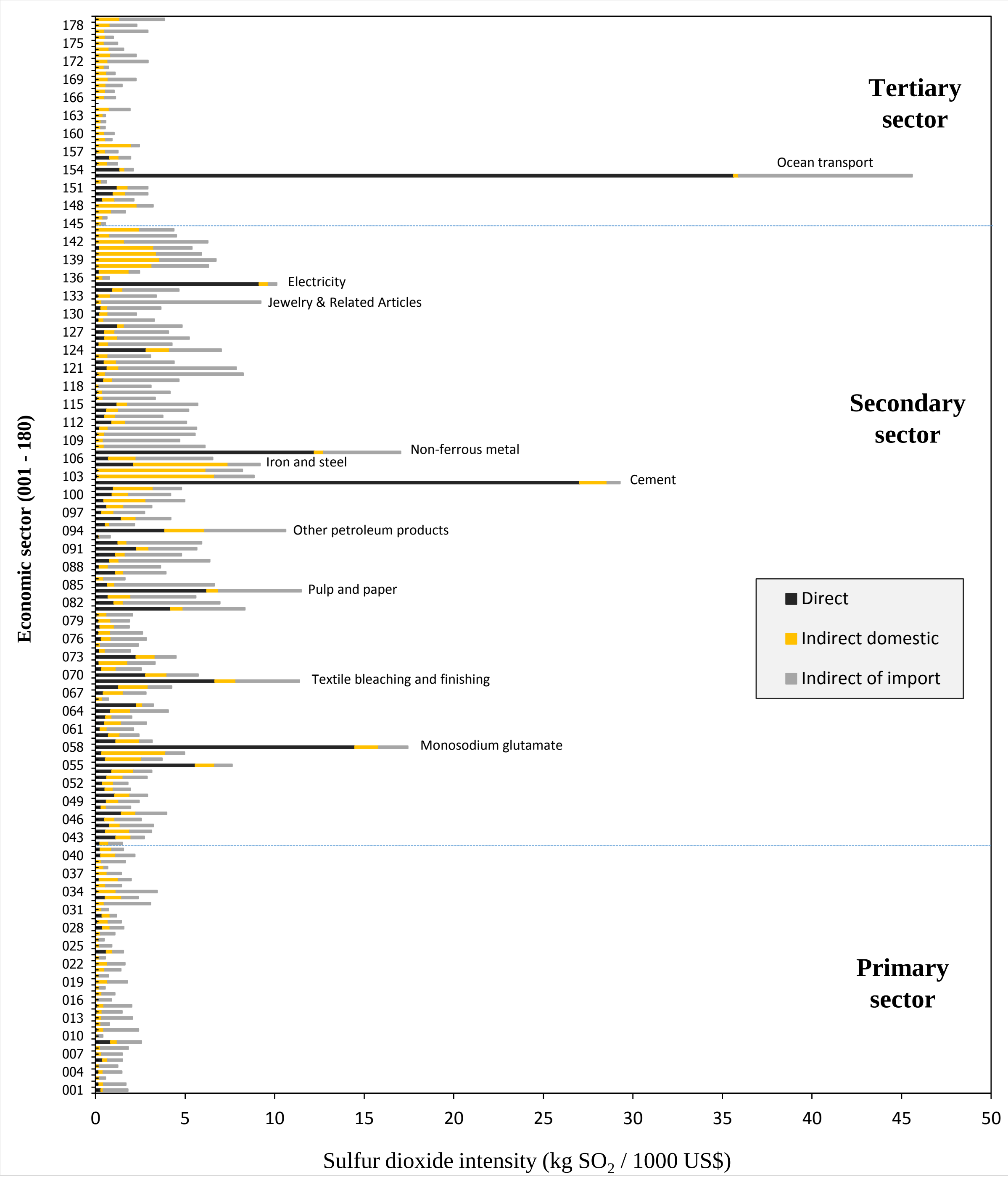

Figure 3-6. SO_2 intensity of Thailand by economic sector using the 2005 THIO table.

3.3.2.2 Sulfur dioxide footprint

Figure 3-7 shows the top 10 sectors for SO_2 footprint based on the domestic consumption of Thailand in 2005. The total SO_2 footprint was approximately 0.532 million tonnes SO_2 or 8.51 kg SO_2 per capita. Compared to the SO_2 intensity, the ranking changes and the most important SO_2 intensive sector is the electricity sector (0.129 million tonnes SO_2.). The next are the non-ferrous metal (0.081 million tonnes SO_2), basic industrial chemical (0.073 million tonnes SO_2), cement (0.062 million tonnes SO_2), iron and steel (0.024 million tonnes SO_2), pulp and paper (0.021 million tonnes SO_2), other petroleum products (0.013 million tonnes SO_2), secondary steel products (0.010 million tonnes SO_2), sugar (0.008 million tonnes SO_2), and clothing sector (0.006 million tonnes SO_2).

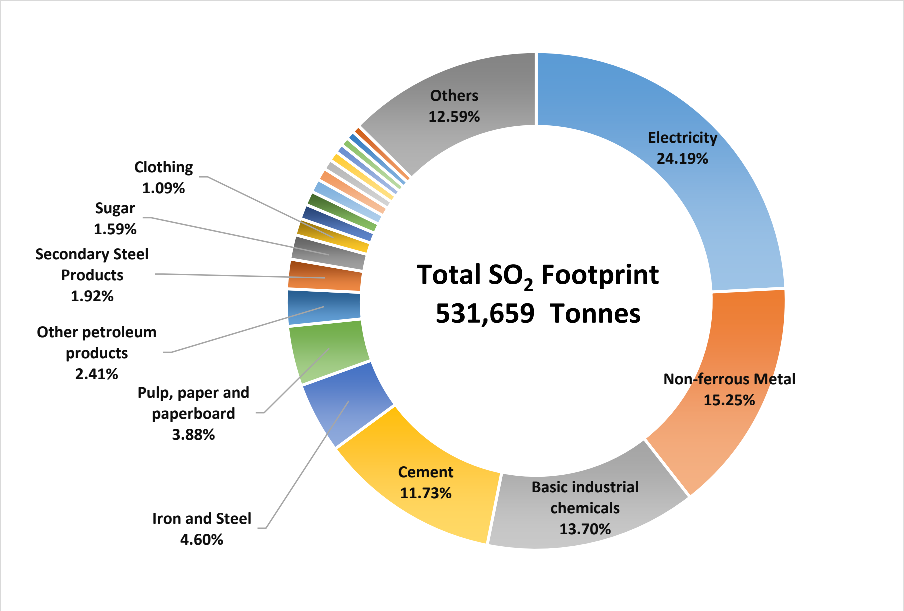

Figure 3-7. SO_2 footprint of Thailand based on domestic consumption in 2005.

3.3.3 Nitrogen oxides (NOx)

3.3.3.1 Nitrogen oxides intensity

The total NOx intensity from 180 industrial sectors of Thailand is presented in Figure 3-8. The largest NOx intensity is for the ocean transport sector accounting for 90.27 kg NOx per 1000 US$ output. The highest intensity in this sector was due to the fuel oil combustion in the engines without controlled emissions. The next was the road freight transport (42.28) followed by the railways transport (29.71), coastal and inland water transport (27.44), cement (26.77), electricity (13.90), sugar milling (12.15), sugarcane (11.98), air transport (11.93), and non-ferrous metal (11.46). The result shows that half of the top 10 intensive sectors are from the transportation sector. This is due to the fact that the NOx emissions from mobile sources are difficult to control and it is hard to mitigate the emission at the tailpipe of vehicles.

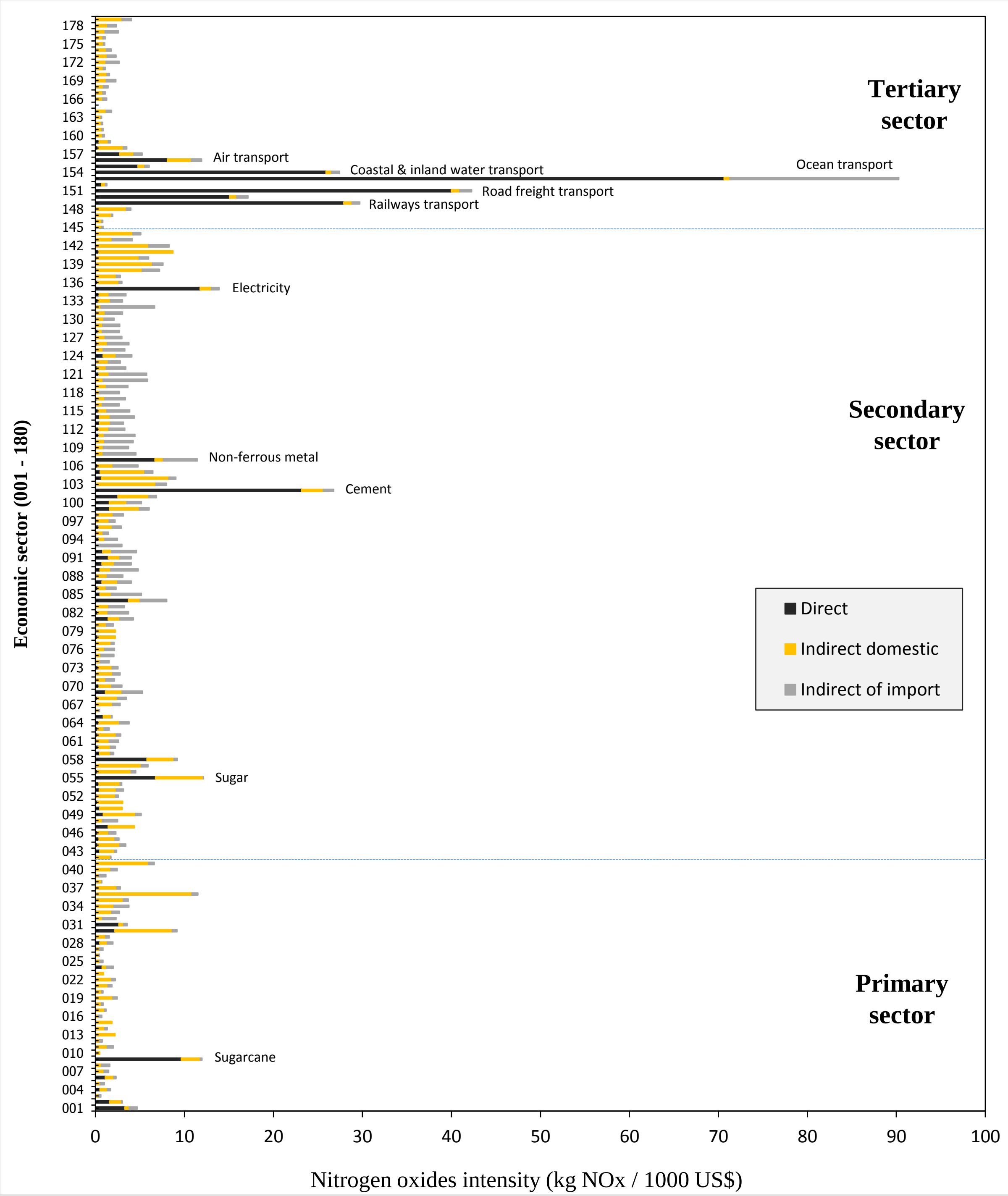

Figure 3-8. NOx intensity of Thailand by economic sector using the 2005 THIO table.

3.3.3.2 Nitrogen oxides footprint

Figure 3-9 shows the results of the top 10 sector for NOx footprint of Thailand based on domestic consumption in 2005. The total NOx footprint was approximately 0.734 million tonnes NOx or 11.75 kg NOx per capita. The most important NOx intensive sector was the electricity sector (0.166 million tonnes), followed by the road freight transport (0.114 million tonnes), road passenger transport (0.071 million tonnes), crude oil and natural gas (0.069 million tonnes), cement (0.053 million tonnes), non-ferrous metal (0.044 million tonnes), basic industrial chemicals (0.043 million tonnes), coastal and inland water transport (0.035 million tonnes), air transport (0.024 million tonnes), and paddy sector (0.018 millions). This change may be explained by the high final demand of the electricity, paddy, road passenger transport, non-ferrous metal, and basic industrial chemical sectors that indicate a medium NOx intensity. The high NOx intensive are in the electricity, road freight transport, road passenger transport, crude oil and natural gas, cement, non-ferrous metal, basic chemical, inland water transport, and air transport sectors due to the impacts from fossil fuel combustion in the boilers and combustion engines in these sectors. While, the paddy sector is come from rice straw combustion in the fields.

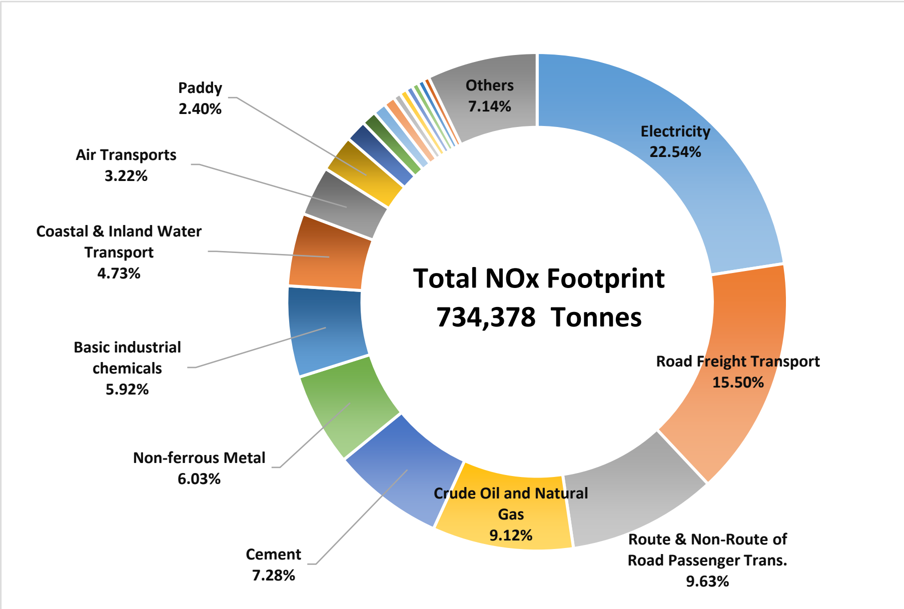

Figure 3-9. NOx footprint of Thailand based on final consumption in 2005.

3.3.4 Particulate matter (PM10)

3.3.4.1 Particulate matter intensity

Figure 3-10 shows the PM10 intensity of 180 industrial sectors in 2005. Based on 1000 US$ output, the highest PM10 intensity sector is sugarcane accounting for 16.68 kg PM10. The highest intensity in this sector was due to the pre-harvest burning of the sugarcane fields. The next are the paddies (13.88 kg PM10), beans and nuts (13.71 kg PM10), rice milling (11.4 kg PM10), animal oil and vegetable oil (10.57 kg PM10), cement (8.07 kg PM10), ocean transport (7.16 kg PM10), cassava (7.08 kg PM10), sugar (6.23 kg PM10), and monosodium glutamate sector (5.85 kg PM10).

The PM10 intensity in the agricultural sector (paddy, beans and nuts, sugarcane, and cassava) was more than other sectors due to these sectors be involving open burning of biomass in the fields. While, rice milling, animal oil and vegetable oil, sugar, and monosodium glutamate sectors have high PM10 values due to the indirect effect from agriculture feedstock. The cement sector is a high intensity sextor due to coal combustion and emission from the production processes. The ocean transport sector is high intensity because of the fuel oil combustion without controlled emissions.

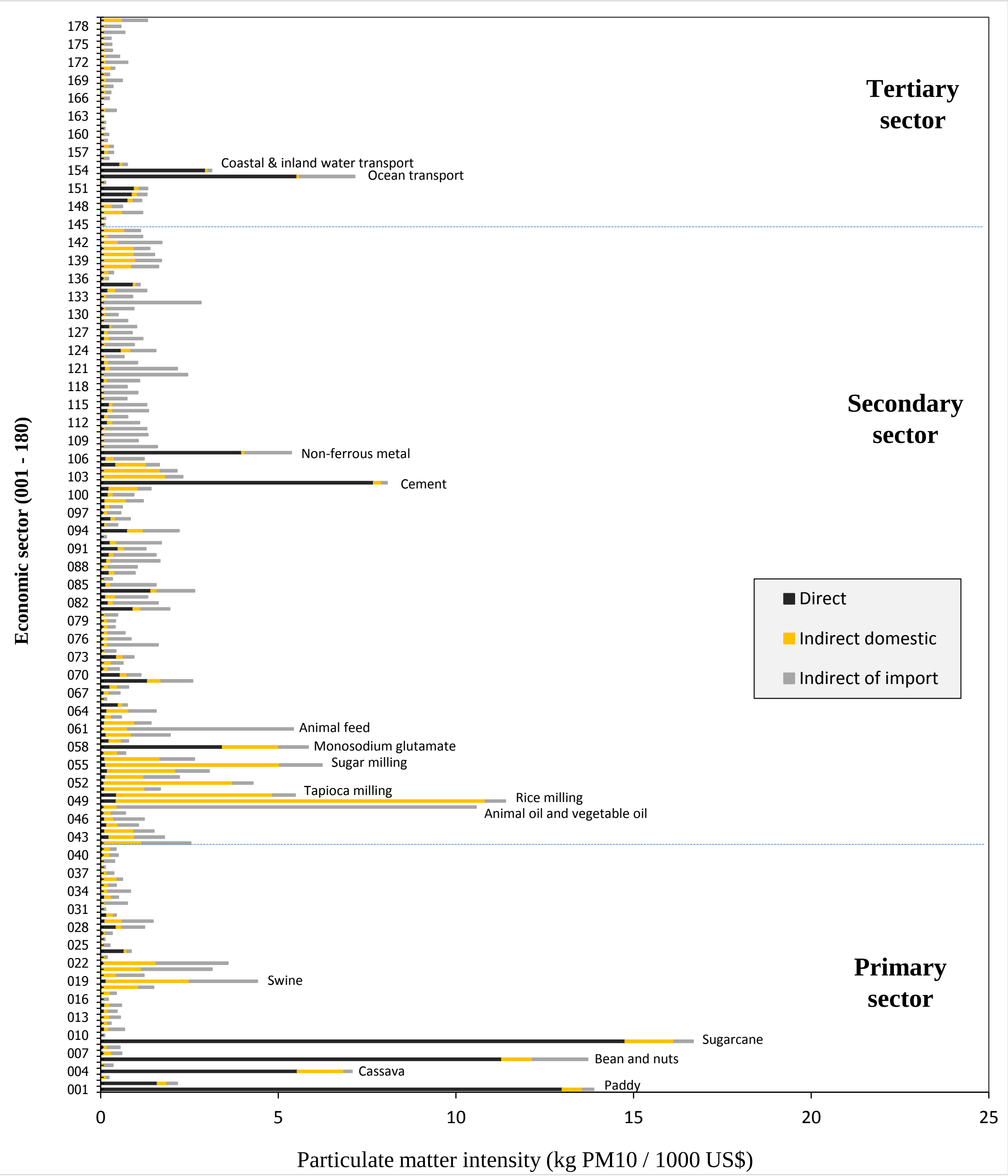

Figure 3-10. PM10 intensity of Thailand by economic sector using the 2005 THIO table.

3.3.4.2 Particulate matter footprint

Figure 3-11 presents the result of the PM10 footprint for each economic sector of Thailand, based on the domestic consumption in 2005. The total PM10 footprint was approximately 0.170 million tonnes PM10 or 2.72 kg PM10 per capita. The most important PM10 intensive sector is the paddy sector (0.030 million tonnes), followed by the non-ferrous metal (0.026 million tonnes), cement (0.018 million tonnes), basic industrial chemicals (0.017 million tonnes), electricity (0.013 million tonnes), sugarcane (0.011 million tonnes), iron and steel (0.005 million tonnes), and pulp and paper sector (0.004 million tonnes). When comparing with the PM10 intensity, the ranking changes may be explained by the high final demand of the non-ferrous metal, basic industrial chemicals, electricity, iron and steel, pulp and paper, and road passenger transport sectors that indicates the smaller PM10 intensity of these sectors. At the same time, the small final demand of the sugarcane and paddy sectors indicate higher PM10 intensities.

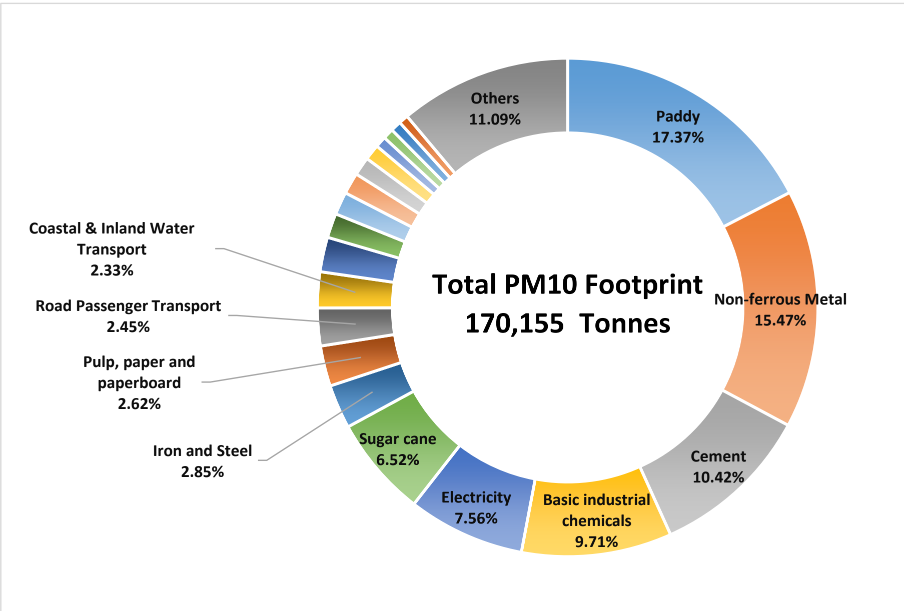

Figure 3-11. PM10 footprint of Thailand based on final consumption in 2005.

3.4 Discussions

Emission intensities by economic sectors can be used as a suitable indicator presenting the level of emission technology. This study compares three different emission intensities (GHGs, SO_2 and NOx) for each sector between Thailand and Japan in Figure 3-12 to Figure 3-14.

1) Comparison the GHGs intensity between Thailand and Japan

Comparison has been made to examine the results of GHGs emission intensity between Thailand and Japan. The Figure 3-12 presents that GHGs intensity of all agriculture sectors (crops, forestry, livestock, and fishery) in Thailand were higher than in Japan (Nansai et al., 2012). Estimation of GHG emissions in the cattle and paddy sectors were based on the IPCC guidelines. However, the cattle and paddy sectors were about 10 times higher than in Japan.

This is mainly because these sectors in Thailand produce higher CH_4 emission from rice cultivation and enteric fermentation of the ruminant animals. In addition, there are a variety practices in the rice cultivation and the contribution in monetary value of both sectors is very low in the Thai economy (OAE, 2009).

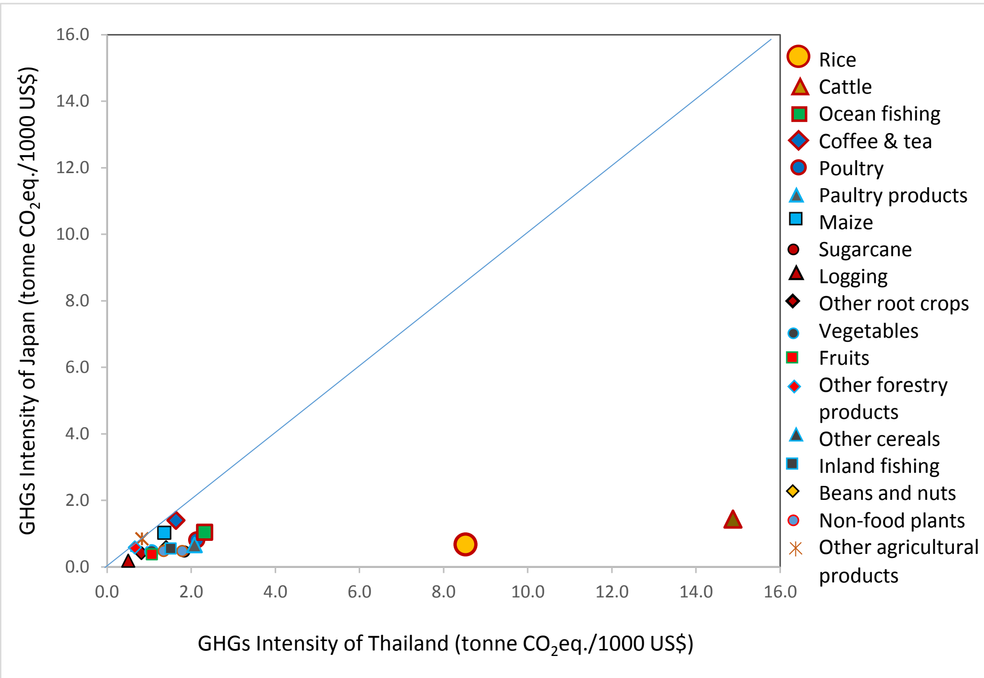

Figure 3-12. Comparison the GHGs intensity in agriculture sector in Thailand and Japan.

The result show the large gaps in the rice and cattle sectors between Thailand and Japan. Types of rice cultivation in each country are different, and the reason of discrepancy may be different types of rice. Regarding the rice cultivation and cattle sectors, there are no official statistics on CH_4 emission from rice cultivation and enteric fermentation in Thailand. Estimation of direct CH_4 emission were carried out using the emission factor from the IPCC guidelines, which is limited information with high uncertainty. It seems to be necessary to develop the CH_4 emission coefficients in Thailand for the estimation of CH_4 emission in rice cultivation and enteric fermentation.

In addition, we can verified the GHG intensity database (kg CO_2 eq./US$) in the paddy rice sector of Thailand and Japan by multiply with the producer price of paddy (US$/kg paddy) at farm gate of each country. The result showed that the GHG emissions of paddy rice in Thailand are approximately 10% higher than Japan case. When comparing with others case studies in Thailand, the result presented that the GHG emissions of paddy rice in this study is a same range of other studies in Thailand. The result was shown in Figure 3-13.

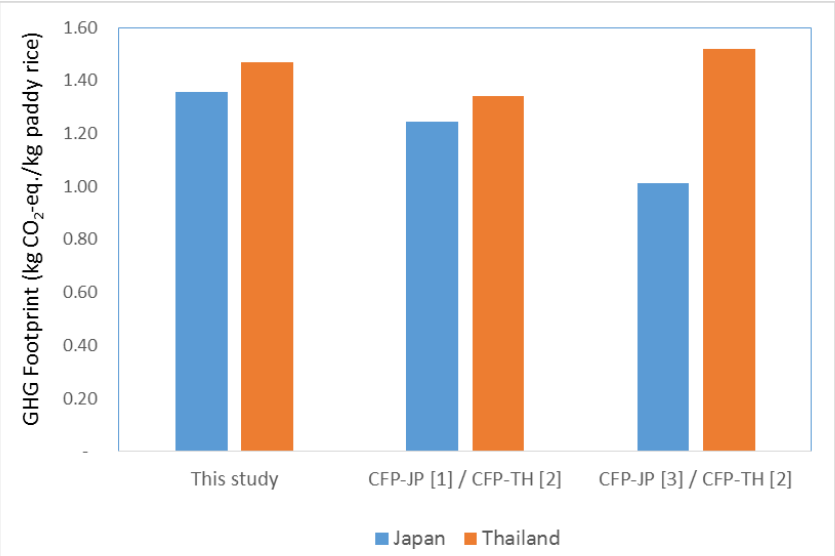

Figure 3-13. Comparison the GHGs emissions of paddy rice in Thailand, Japan, and other studies.

Remark: [1] Kawashima & Yoshikawa (2010); [2] Yodkhuma & Sampattagula (2014); [3] AEON Co., Ltd.

2) Comparison the SO_2 intensity between Thailand and Japan

The Figure 3-14 shows the SO_2 intensity of crops (except other cereals and other agricultural products), poultry and poultry products, and the logging sector in Thailand were higher than in Japan (Nansai et al., 2012). While the ocean fishing, inland fishing, other cereals, other agricultural products, cattle, and other forestry products sectors were higher in Japan than in Thailand. Estimation of SO_2 emissions in this study were calculated using the emissions factor rom the IPCC guidelines. However, the ocean and coastal fishing sector in Japan is about 8 times higher than in Thailand. This sector, in Thailand, is the most small-scale fisheries, whereas in Japan is the commercial-scale fisheries and import from other countries. Total aquaculture production in Japan corresponds to 22% of total national fisheries production. Marine aquaculture can be divided into intensive aquaculture (fish), and extensive aquaculture (shellfish and seaweed). Marine aquaculture accounts for 96% of total aquaculture production in Japan (FAO, 2009a). While in Thailand, 58.2% of total fishery production came from marine capture fisheries, followed by coastal aquaculture (22.9%), freshwater aquaculture, (13.1%) and inland capture fisheries (5.8%), respectively. For the marine fisheries, the commercial fishing vessels contributed up to 90% of the marine catch (FAO, 2009b).

The inland fishing sector in Japan is about 3 times higher than in Thailand. In Thailand, the inland capture fisheries are small-scale enterprises, which are carried out principally in rivers, lakes, swamps and reservoirs. These fisheries have long been a part of Thai culture in the rural area (FAO, 2009b). While, in Japan is the commercial-scale fisheries and freshwater aquaculture is conducted in all 47 Japanese prefectures (FAO, 2009a).

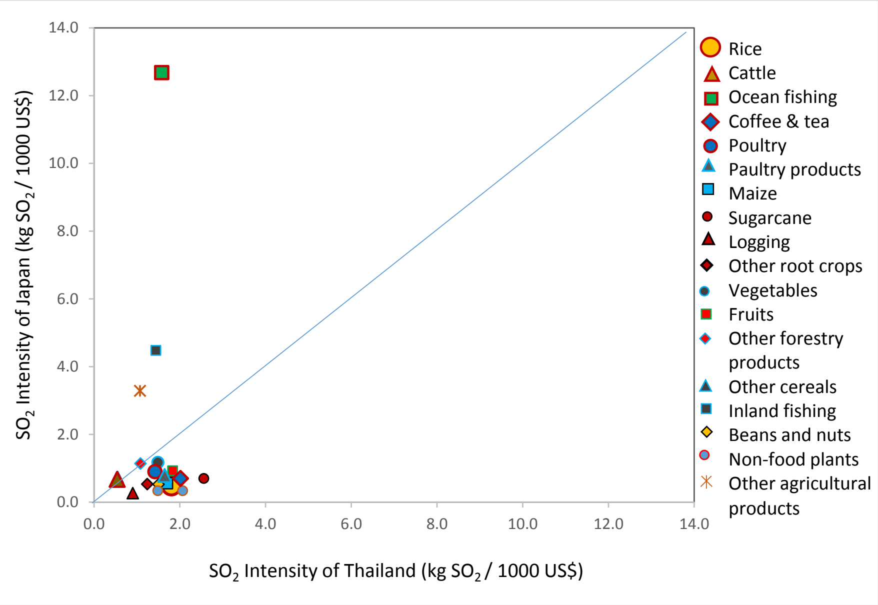

Figure 3-14. Comparison the SO_2 intensity in agriculture sector in Thailand and Japan.

3) Comparison the NOx intensity between Thailand and Japan

The Figure 3-15 shows that the NOx intensity of crops (except other cereals and other agricultural products), poultry and poultry products, and logging sector in Thailand were higher than that in Japan (Nansai et al., 2011). While the ocean fishing, inland fishing, other cereals, other agricultural products, cattle, and other forestry products sectors in Japan higher than Thailand. The trend of result is similar to SO_2 intensity. Estimations of NOx emissions in this study were also calculation based on the IPCC guidelines. The ocean and coastal fishing sector, the NOx emission intensity of Japan is about 5 times higher than Thailand. For the inland fishing, the NOx intensity of Japan is higher than Thailand about 2 times. Due to the same reasons mentioned of the SO_2 intensity is explained in the previous section.

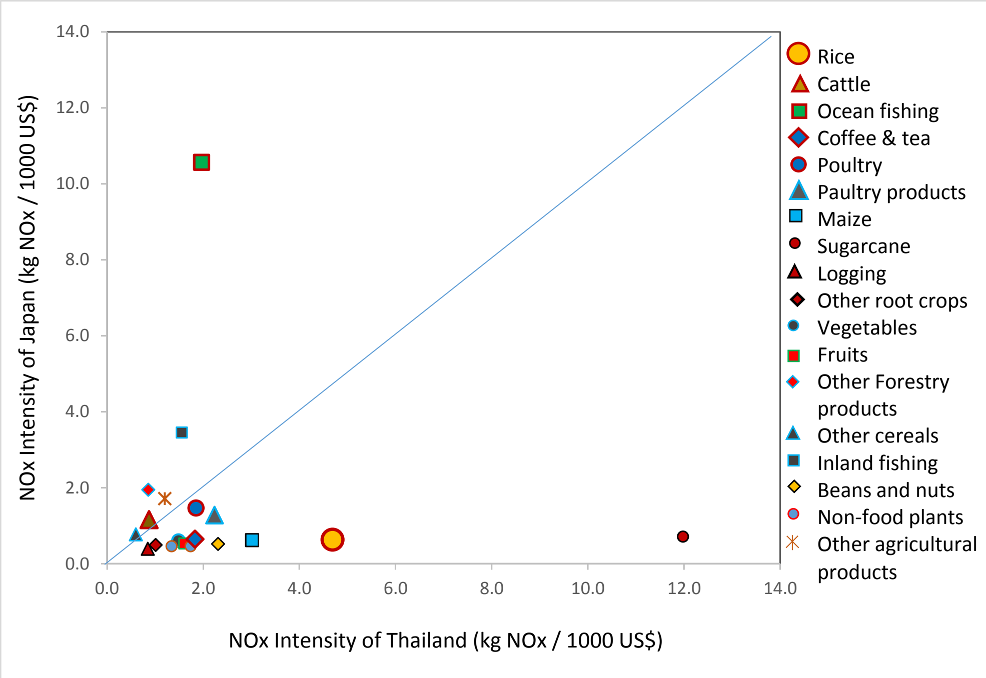

Figure 3-15. Comparison the NOx intensity in agriculture sector in Thailand and Japan.

The result shows large gaps of rice and sugarcane sectors between Thailand and Japan. The agriculture operation practices in each country are different. Regarding the rice cultivation and sugarcane harvesting, there are open burned the rice straw for preparing the next cultivating and pre-burning sugarcane before cutting. While in Japan is not burned the agricultural residues. Estimation of direct NOx emission for burning the agricultural residues were made by using the emission factor from the IPCC guidelines and the restudied in Thailand.

3.5 Sensitivity analysis

3.5.1 Change in energy prices (coal price) effect on NOx intensity

In order to evaluate the impact of changes of the energy price in the cement, pulp and paper, and non-ferrous metal sectors on the NOx emission intensity, taking into consideration the sensitivity analysis was performed as follows:

- Base case scenario (S0): the coal price per unit energy of each industrial sector is same in all sectors.
- Scenario 1 (S1): changes of +10% coal price in the cement, pulp and paper, and non-ferrous metal sectors.
- Scenario 2 (S2): changes of +20% coal price in the cement, pulp and paper, and non-ferrous metal sectors.

- Scenario 3 (S3): changes of –10% coal price in the cement, pulp and paper, and non-ferrous metal sectors.
- Scenario 4 (S4): changes of –20% coal price in the cement, pulp and paper, and non-ferrous metal sectors.

The results of the sensitivity analysis done for five scenarios of the change in energy price effect on the NOx emission intensity are showed in Figure 3-16. This result presented as percentages relative to the base case scenario (S0). It can be verified that among the studied variables, all scenarios present the less significant impact on the NOx emission intensity in the manufacturing sector.

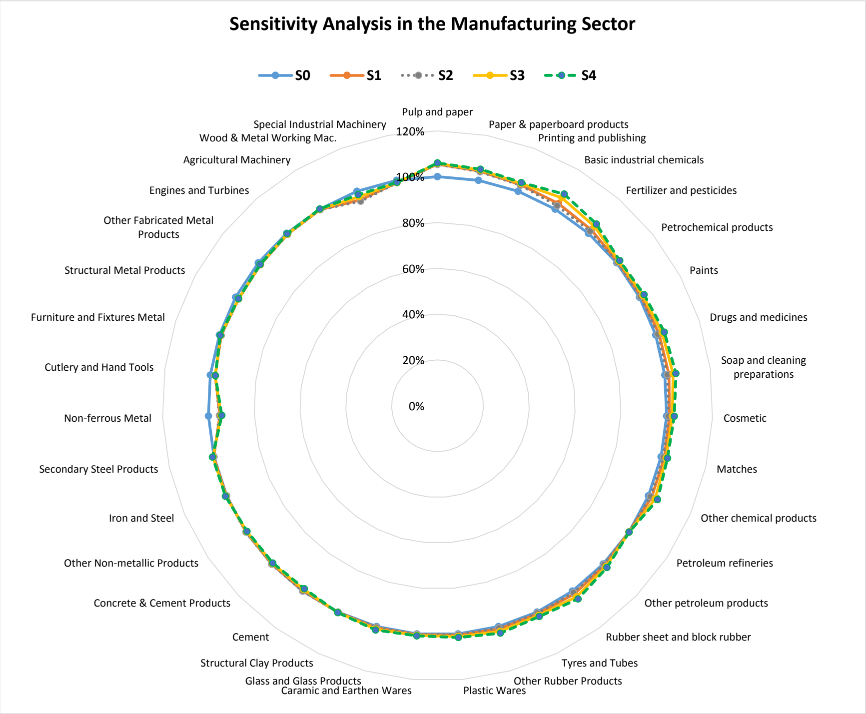

Figure 3-16. Sensitivity analysis of the change of coal price in the cement, pulp and paper, and non-ferrous metal sectors on the NOx emission intensity.

3.5.2 Change in the system boundaries effects on NOx emission intensity

In order to evaluate the impact of changes of system boundary on the NOx emission intensity of Thailand, taking into consideration the sensitivity analysis were carried out as follows:

- Base case scenario (THIO-included import): evaluate the NOx emission intensity using the THIO table by including the effects from import.
- Scenario 1 (THIO-excluded import): evaluate the NOx emission intensity using the THIO table by excluding the effects from import.

The results of the sensitivity analysis done for two scenarios effect on the employment intensity of Thailand are shown in Figure 3-17 to Figure 3-18. This result presented as percentages relative to the base case scenario (THIO-included import). It can be confirmed that the import effect shows the high significant impact on the NOx emission intensity in all sectors of the agriculture and manufacturing sectors, particularly in the economy sector that rely on raw materials from other countries.

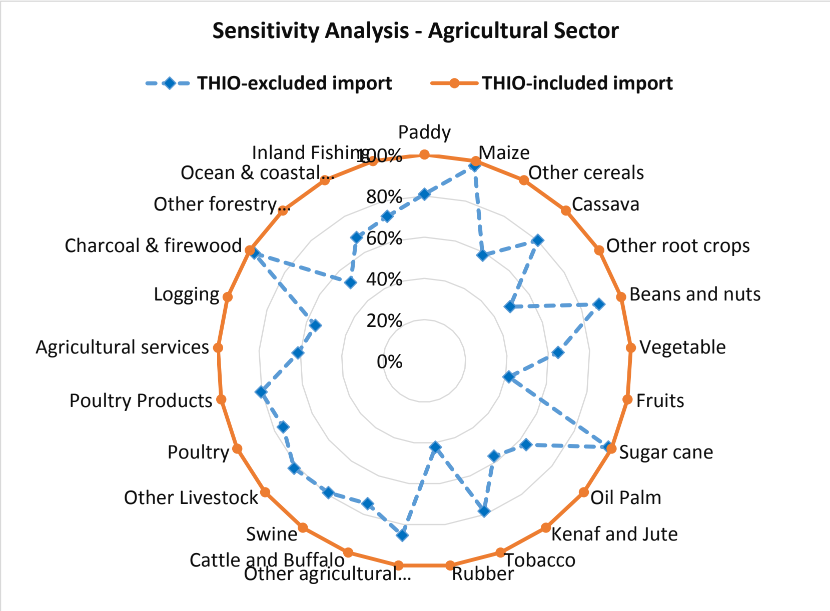

Figure 3-17. Sensitivity analysis of change in the system boundaries effects on the NOx intensity in agricultural sector.

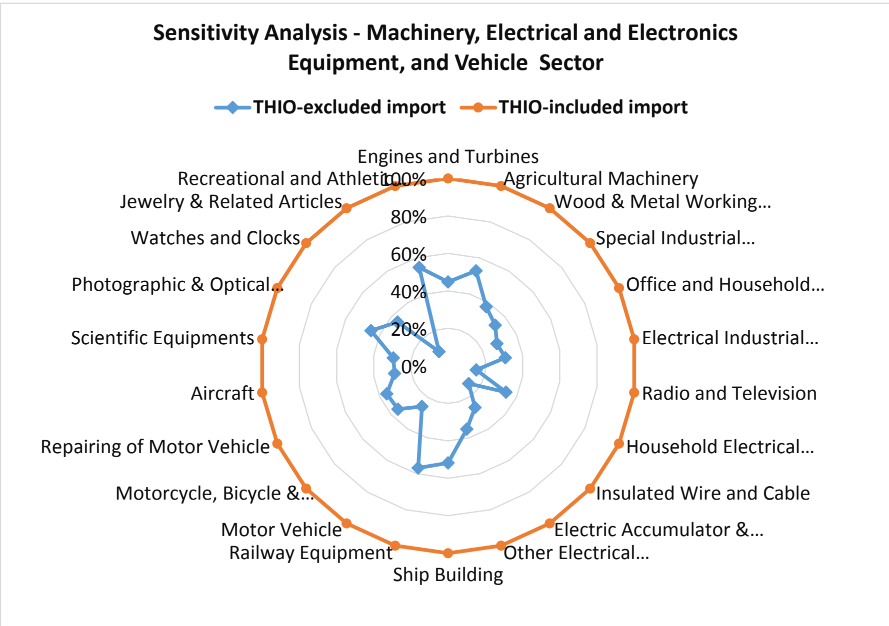

Figure 3-18. Sensitivity analysis of change in the system boundaries effects on the NOx intensity in the machinery, electrical and electronics equipment, and vehicle sectors.

From the sensitivity analysis, the most important parameter that effect on the NOx intensity is the change in the system boundaries by excluding the effects from imported products. It is very interesting to see from the Figure 3-17 and Figure 3-18 that the NOx intensity changes from 20% to 60% in comparison to the base case scenario.

3.6 Conclusions

3.6.1 Summary

1) GHGs emissions in the secondary sector have 78.5% direct GHGs shared out of the total GHG emissions in the country. The most of crops have higher direct GHGs intensities at most sectors. Most of secondary sector produced higher indirect GHGs intensities except cement, electricity, tapioca milling, coconut and palm oil, non-ferrous metal, gas separation and distribution, and monosodium glutamate sector. The indirect GHG effect in these sectors mainly comes from energy consumption in the process. In the tertiary sector, the direct GHGs intensities are highest in the transportation sectors.

2) SO_2 emissions in the secondary sector have 95% direct emissions share out of total SO_2 emissions in the country. The most of crop sectors have higher indirect SO_2 intensities. While, the secondary sector is dominated direct SO_2 intensities in the cement, electricity, non-ferrous metal, monosodium glutamate, pulp and paper, and textile bleaching and finishing sector. In the tertiary sector, the direct SO_2 intensity is highest in the ocean transport sector.

3) NOx emissions in the secondary sector have higher than 98% direct emissions share out of total NOx emissions in the country. The most of crop sectors have higher indirect NOx intensities except sugarcane and paddy. While, the secondary sector is dominated direct NOx intensities in the cement, electricity, non-ferrous metal, and sugar milling sector. For the tertiary sector, the direct NOx intensity is highest in all transportation sector.

4) In the life cycle perspective view, GHGs management considering indirect GHG emissions in the supply chain, is important to increase energy efficiency. More than 35% of total GHGs were indirect GHGs by final demand. The indirect GHG management may contribute smart management of GHG in the whole life cycle.

5) The GHGs, SO_2, NOx, and PM10 intensity database using input-output analysis can be used for the environmental footprint scheme with life cycle thinking. It can provide the fundamental dataset to introduce the environmental footprint scheme in Thailand. It seems to be important to consider GHGs, SO_2, NOx, and PM10 emissions in the whole supply chain.

6) It is not easy to quantify all issues and all sectors for sensitivity analysis in the database. However, in the sensitivity analysis of the agriculture and manufacturing sector focused on the change in the system boundary seems to be important to influence on the NOx emission intensity accounting in Thailand. Furthermore, polishing of direct NOx emission intensity in the manufacturing sector may increase the precision of NOx intensity database since the direct NOx intensity is a critical element in the NOx footprint database in Thailand.

3.6.2 Limitations and further studies

1) It should improve the economic contribution for some sector in the IO analysis. For example, the total number of cattle and buffalo in Thailand are 7.9 million heads, but economic cattle and buffalo are about 50% of the animals. The number of cattle and buffalo production for the dairy and slaughtering sector are 1.8 million heads. It is not easy to determine apart economic sharing in the IO analysis due to the lack of accurate data on the cattle and buffalo classified for this kind of assessment.

2) Actually, many sectors in Thailand have larger indirect environmental (GHGs, SO_2, NOx, and PM10) emission intensities than direct emission intensities. Since, these findings are important to decision-makers to seek practical mitigations on emission reduction from the pollutant intensive industry and relevant industries of Thailand.

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Chapter 4. Development of Social Inventory Database using Thailand Input-Output Table

4.1 Introduction

The three dimensions for sustainable development are environmental, social, and economic issues, with the ultimate goal being human well-being of both the current and future generations. Over the past 15 years (1999–2013), Thai GDP has grown 4.5% a year on average. Although some periods of economic crisis, the economy has proven to be recover to solid economic fundamentals. However, social problems are increasing both in regards to living standards and quality of life. In addition, this results in increasing impacts in the up-stream and down-stream economic sectors of the economy. Current research activities in Thailand have focused on energy and environmental assessment of products and services. In the last two decades, the annual average increase in the ratio of energy consumption value to GDP in Thailand has exceeded 100%. In 2012, the ratio was 18.8% higher than the previous year, whereas in 1990 it was only 11% (NESDB, 2015). This increase in energy consumption is also expected to result in greater environmental impacts on the environment. In Thailand, fossil fuel energy resources are limited and their use is associated with a number of negative environmental impacts. However, energy has become an important socio-economic issue that puts pressure on all countries in the world to improve energy efficiency and develop renewable energy resources.

In Thailand, the relationship between economic growth, employment, and occupational health and safety has been investigated. The Thai Government has recognized the importance of occupational safety and health (OSH) issues in its National Agenda "Decent Safety and Health for Workers". The agenda aims to reduce and prevent occupational accidents and illnesses in the workplace. The OSH Master Plan was developed to provide directions for the development of OSH in Thailand. It is necessary for continual collaboration between relevant stakeholders, including both public and private sectors, so as to enhance safety and health at workplaces in all sectors (Ministry of Labour, 2012). In addition, important social issues are female employment, working hours, wages and salaries, and health care cost.

To understand the embodied impacts of each economic sector on employment, working hours, wages and salaries, and occupational health and safety, this study developed the social inventory database based on input–output (IO) models regarding Thailand's 2005 economic IO tables. The social issues included employment, number of female employees, working hours, wages and salaries, fatal accident and non-fatal accident cases).

4.2 Methodology

4.2.1 Social inventory database development based on IO model

The IO model is widely applied to conduct national economic analyses and is used to assess macro-economic impacts of production change. This study uses the 2005 IO table of Thailand which consists of 180 × 180 sectors in the analyses by aggregating it into a new format (96 × 96 sectors) to match the sector divisions used with the published data on employment, working hours, wages, and occupational safety. The aggregation was based on the proportion of each economic sector output. The assumption of homogeneity implies that each activity in a homogenous aggregated sector *j* requires the same inputs per unit of output from the aggregate sector *i*. In other words, the homogeneous sectors are considered to produce only primary products, the secondary production being not considered. Definition of economic sectors for the new aggregated IO table (96 × 96 sectors) are shown in Table B-1, in the Appendix B. The calculation steps of the social footprint intensity database are presented in Figure 4-1.

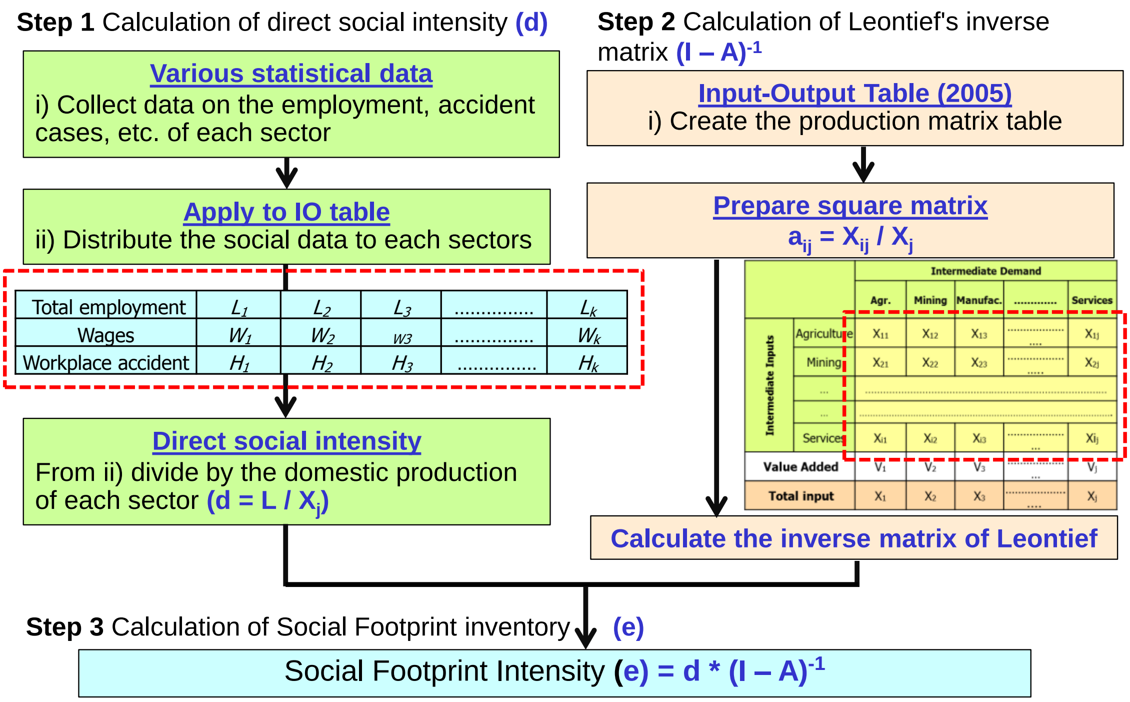

Figure 4-1. Calculation steps of the social footprint intensity database using Thailand IO table.

The first step is to estimate direct labor input (d) at all economic sectors and to allocate the labor input to each sector in the 96 economic input-output table code. The second step is to prepare Leontief inverse matrix from the I-O table based on the producer matrix table. The final step is to multiply direct labor input by the inverse matrix.

4.2.1.1 Assumptions and limitations

The applying IOA in this study involves some assumptions summarized in the following:

- Constant technological coefficients: the amount of input necessary to produce one unit of output is assumed to be constant in the short term, regardless to price effects, changes in technology or economies of scale.
- Linear production functions: the IOA assumes that if the output level of industry changes, the input requirements will change proportionally.
- It is assumed that each economic sector produces and sells one and only one homogeneous good.
- There are no resource constraints. Supply is assumed infinite and perfectly elastic.
- Local resources are efficiently employed. There is no underemployment of resources.
- IO tables describe an economy in a specific period; they do not highlight the trend of the economic interrelationship in a long time.
- This study was considered effect within domestic and import from the rest of the world (RoW). Imports from the RoW implicitly assumes that the same production characteristics and technologies as comparable products made in Thailand. It is also assumed in this model that RoW have the same technology, and although there are the difference between the domestic or import commodity price. We assumed that other countries have the same technology and direct social coefficients as the country analyzed. In this case, the social impact embodied in imports can be defined as the foreign social impacts represent the actual impact generated by Thailand.

4.2.1.2 Calculation of direct social intensity

The modified IO model adds a row for social aspects to show the social issues involved in production processes, thus quantifying the social footprint for the final demand in different sectors. The social footprint matrix (d) is the extension of the direct input coefficient matrix for social issues. Where d is a $k \times j$ matrix, L_{kj} is social issue k (e.g., employment, accident cases) per monetary output of sector j. The matrix d is defined as:

$$d = d_{kj} = L_{kj} / X_j \qquad (k = 1,\ldots, m;\ j = 1, \ldots , n) \tag{4-1}$$

This study analyzes six different social impacts, the dimensions of the social aspects matrix are d (6 × 96). Elements in the social aspects matrix reflect the impacts per sectoral output, e.g., 100 working-hours per 1000 Thai Baht for the paddy rice sector.

4.2.1.3 Calculation of Leontief's inverse matrix

The direct input coefficient is the ratio of the intermediate demand inputs (sales from sector *i* to sector *j*) (X_{ij}) and the total output of sector *j* (X_j). The set of input coefficients of all economic sectors is expressed in the square matrix A (n x n), which is called the direct input coefficient matrix. n is the number of sectors or the dimension of economic system. The matrix A defined as:

$$A = a_{ij} = X_{ij} / X_j \qquad (i, j = 1, \dots, n) \qquad (4\text{-}2)$$

so that in matrix notation equation (4-2) becomes

$$x = Ax + Y \qquad (4\text{-}3)$$

Solving for x yields

$$x = (I - A)^{-1} Y \qquad (4\text{-}4)$$

where I is the identity matrix (n x n), Y is the vector of final demand, and $(I - A)^{-1}$ is called the Leontief inverse matrix.

Since the time and statistics are data limitations, similar sectors are often aggregated or merged for all individual outputs into one aggregated output. This study developed the input coefficient matrix based on the 2005 economic IO table of Thailand with aggregated data for 96 × 96 economic sectors.

4.2.1.4 Calculation of total social impacts

The total social impact vector (f) of goods or services *versus* a given amount for economic demand is

$$f = dx = d\,(I - A)^{-1}\,Y \qquad (4\text{-}5)$$

where A is the direct input coefficient matrix (calculated by dividing the industry-by-industry direct requirements of sectoral inputs by the sectoral output); I is the identity matrix; d is the social footprint matrix; and Y is the final demand vector. $(I - A)^{-1}$ is the matrix of input–output multipliers and shows the total effects (direct and indirect) on sectoral production caused by unitary changes in the final demand of sectors.

4.2.2 Data processing

This study developed the social inventory database based on the IO model using Thailand 180-sector input–output table in 2005 (NESDB, 2014). The social inventory established in this study included employment, working hours, wages and salaries, occupational accidents and fatalities. The summary of social indicators used in this study is presented in Table 4-1.

Table 4-1. Summary of social indicators used in the study.

Measure	Indicators	Unit	Definition	Data Source	Data Year
Employment	Total employment	Persons-year	Total employment required for the production of goods and services	NSO (2006)	2005
Working hours	Worked hours	Hours-year	Total number of hours actually worked per year for the production of goods and services. Actual hours worked include regular work hours of full-time, part-time workers, self-employed workers, and exclude time not worked.	BOT (2014)	2005
Wages and salaries	Income	Million Thai Baht	The compensation by employers to employees. Employees are classified as long-term workers, temporary workers, executives and hired laborers in the agricultural sector, but excluded family workers.	NSO (2006) NSO (2007) NSO (2007)	2005 2006 2006
Fatal occupational cases	Fatal cases in workplace	Cases-year	Cases where workers were fatally injured as a result of occupational accidents, and where death occurred within one year of the day of the accident.	SSO (2006)	2005

Non-fatal occupational cases	Non-fatal cases in workplace	Cases-year	Cases of occupational injury where the workers injured were unable to work temporarily or permanently from the day after the day of the accident.	SSO (2006)	2005

The data mapping steps of the social inventory data into the socially extended input-output model are presented in Figure 4-2.

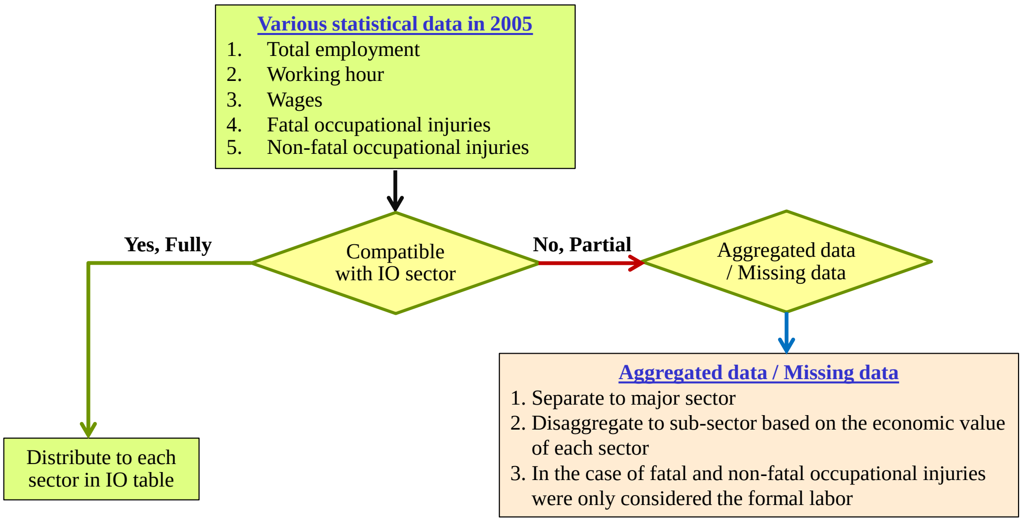

Figure 4-2. Data mapping steps of the social data into the Thailand IO table.

Sectoral total employment is the sum of both formal and informal employment in Thailand gathered from the Labor Force Survey of 2006 (NSO, 2006). However, the published sector based data are limited and fail to reflect the whole picture of employment in Thailand, e.g., farmers are not classified into a sub-sector. In the case of aggregated data, this study allocated the numbers of employment for each sub-sector based on economic value of each sector.

Working hours (WH) for the agriculture sector is classified into two categories: WH of employees and WH of self-employed workers and family workers. WH of employees is calculated from the ratio of the total wage paid by the primary sector from the 2005 IO table and minimum wage rate of each province in the planting of each crop. WH of self-employed and family workers was estimated by work day based on the planting period of each crop and allocated the WH for self-employed and family workers to each crop based on the economic value of each crop. The WH of industrial sectors and service sectors were calculated from the working hour statistic data of Thailand (BOT, 2014). In case of aggregated data, this research allocated the working hours to each sub-sector based on the employment numbers of each sector.

Likewise, the intensity for wages and salaries indicator was calculated. This data are from the 2007 Industrial Census Whole Kingdom of Thailand (NSO, 2007), the 2006 Business Trade and Service Survey of Thailand (NSO, 2006) and the Statistical Yearbook Thailand 2007 (NSO, 2007b).

The database for occupational accidents and fatalities was gathered from Thailand's Social Security Office (SSO, 2006). The database included only formal labor (permanent labor) defined under the Thailand Social Security Act. The database excluded informal labor and public servants. The accident and fatality statistics were allocated to each sector based on sectoral economic outputs.

4.3 Results

4.3.1 Employment

4.3.1.1 Employment intensity

The employment intensity expressed in terms of person-year per million Thai Baht output of 96 industrial sectors is given in Figure 4-3. The largest employment intensity is in paddy rice, accounting for 22.21 person-year/million Thai Baht output. The highest intensity in the paddy crop was attributed to the low economic value of the product with a large amount of labor used in the cultivation. The next was cassava (19.95) followed by beans and vegetables (18.66), sugarcane (18.03), rice milling (17.80), maize and other grain (17.48), tobacco (17.20), fruits (17.01), oil palm (17.00), and coffee and tea (19.95), respectively. Due to the fact that agriculture in a developing country is labor intensive, the agricultural sector has the highest employment intensity in both direct and total intensity excluding livestock and fisheries.

Food and related sectors show six categories out of the top 20: Rice milling and grinding of maize (17.80), animal and vegetable oil (14.75), flour and other grain milling (13.56), tapioca milling (13.48), coconut and palm oil (11.43), and animal feed (11.17). It was shown that the majority of these sectors are agricultural and they are in the food production chain.

From Figure 4-3, it was found that in 2005, direct labor intensity in the agricultural sector was very high. Given high labor employment in this sector, it largely dragged down the country's overall labor productivity. The result showed that the employment intensity in the agricultural sector has greater direct labor intensity, whereas the industrial sector has a higher share of indirect labor. Especially, food processing sectors have a greater portion of indirect labor due to the influences from the primary sector. It may be caused by the impact of food crops as raw materials. More than 50% of labor use was indirect labor in most manufacturing sectors in Thailand. For the tertiary sector, the restaurant and bar sector showed the greatest employment intensity; 54% of the labor is indirect labor. The next was the hotel and guest house sector followed by medical and sanitary services sectors, respectively.

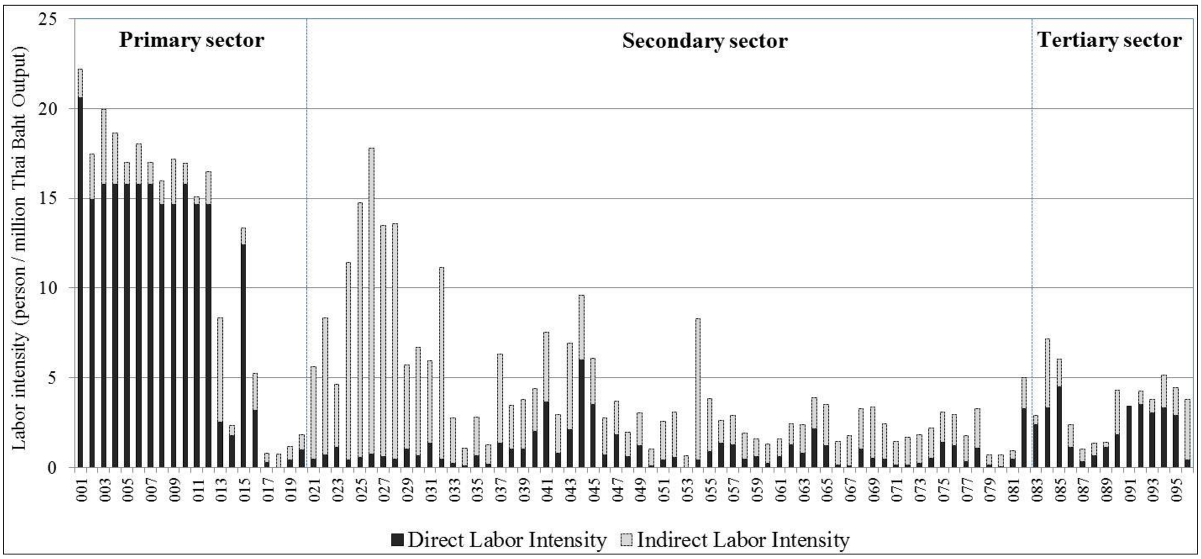

Figure 4-3. Employment intensity of Thailand by economic sector using the 2005 Thailand input-output table.

4.3.1.2 Employment footprint

The results of the total embodied employment or employment footprint are presented in Figure 4-4. Compared to employment intensities, the ranking changes and the most important labor intensive sector becomes the wholesale and retail trade sector (direct 5.24 and total 6.37 million person-year), followed by paddy (direct 3.79 and total 4.09 million person-year), rice milling (direct 0.17 and total 4.01 million person-year), restaurant (direct 1.81 and total 3.90 million person-year), construction (direct 2.13 and total 3.23 million person-year), beans and vegetables (direct 2.45 and total 2.89 million person-year), rubber (direct 2.35 and total 2.41 million person-year), transportation (direct 1.07 and total 2.30 million person-year), fruits (direct 1.94 and total 2.09 million person-year), and radio and television sectors (direct 0.29 and total 1.92 million person-year), respectively. The description of this change is the high final demand of the wholesale and retail trade, radio and television, restaurant, construction, and transportation sectors that imply smaller employment intensity. At the same time, the small final demand of paddy, rubber, beans and vegetables, and rice milling sectors imply a larger intensity of employment. The bigger indirect employment sectors are the rice milling and restaurant sectors due to the agricultural sector using raw materials.

According to the informal labor survey in 2005 (NSO, 2005), the number of informal workers with no social security and protection was estimated at 21.8 million, or 61.5% of the total employed workforce of 35.5 million. About 57% of informal labor or 12.5 million workers were employed in the agricultural sector while 35% and 4% worked in the trade and service sector and manufacturing sector, respectively. In addition, half of employment is considered weak employment, which means being self-employed with no employees or having unpaid family workers.

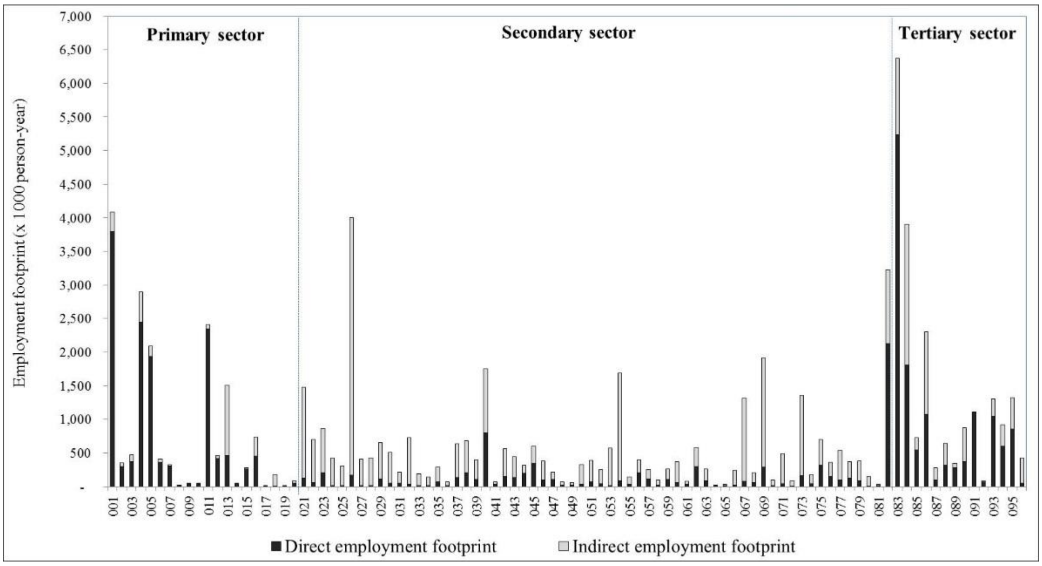

Figure 4-4. Total employment footprint of Thailand by economic sector using the 2005 Thailand input-output table.

4.3.2 Working-hours

4.3.2.1 Working hour intensity

The top 20 in working hour (WH) intensity are in the agricultural and food processing sectors among the 96 industrial sectors, and this is given in Figure 4-5. The largest working hour intensity is maize and other grain accounting for 31,869 h/million Thai Baht output or 15.93 FTE/million Thai Baht output (1 FTE or full time equivalent is estimated 2000 hours/year). The highest intensity in maize and other grain crops were attributed to the low economic value of the product with working hour intensity in the cultivation and harvesting stages. The second highest was cassava followed by paddy, sugarcane, and forestry, respectively.

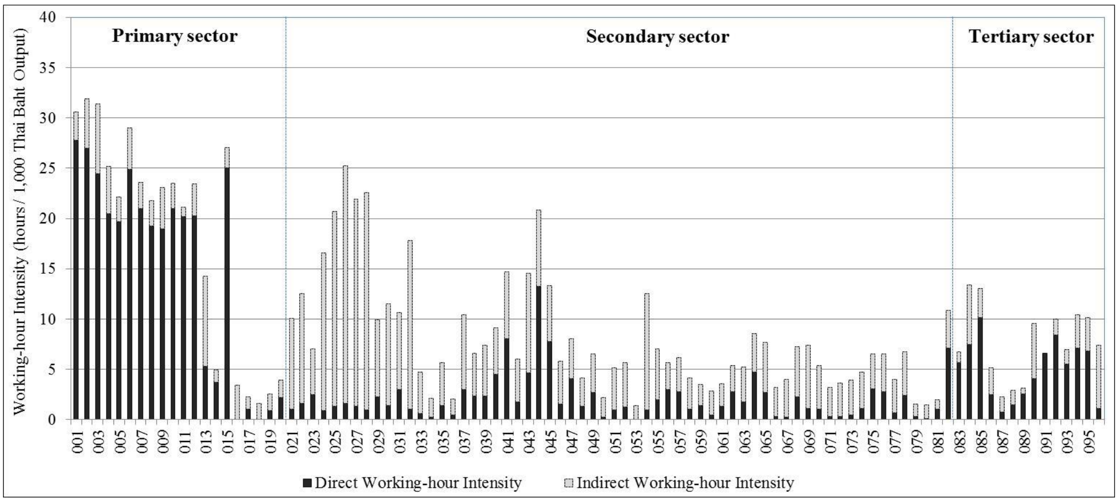

Figure 4-5. Working-hours intensity of Thailand by economic sector using the 2005 Thailand input-output table.

Food and related sectors show six categories out of the top 20: Rice milling and grinding of maize, flour and other grain milling, tapioca milling, animal and vegetable oil, animal feed, and coconut and palm oil, respectively. The majority of these sectors are agricultural, and they are in the food production chain.

The results for working hour intensity show that agricultural sector and service sector had greater direct WH intensity whereas the manufacturing sector had higher share of indirect WH. Especially, the food processing sectors have greater portion of indirect WH though food processing is classified as a primary sector. It may be caused by the impact of the food crops as raw materials. WH patterns vary greatly both in concentration and distribution by sector. Wholesale and retail trade, construction, and service sectors often contribute a large share of WH in the tertiary sector.

4.3.2.2 Working hour footprint

Figure 4-6 shows the result of the working hour footprint by economic sector. Compared to working hour intensities, the ranking changes, and the most important working hour intensive sector becomes wholesale and retail trade, followed by restaurant, construction, rice milling, paddy, transportation, radio and television, beans and vegetables, clothing except footwear, and rubber sectors, respectively. This change may be explained by the high final demand of the wholesale and retail trade, construction, restaurant, radio and television, and transportation sectors that indicates smaller working hour intensity of these sectors. Also, the small final demand of paddy, rice milling, beans and vegetables, and rubber sector indicates bigger working hour intensity. The bigger indirect working hours lie in the rice milling and restaurant sectors due to raw materials being used in the agricultural sector.

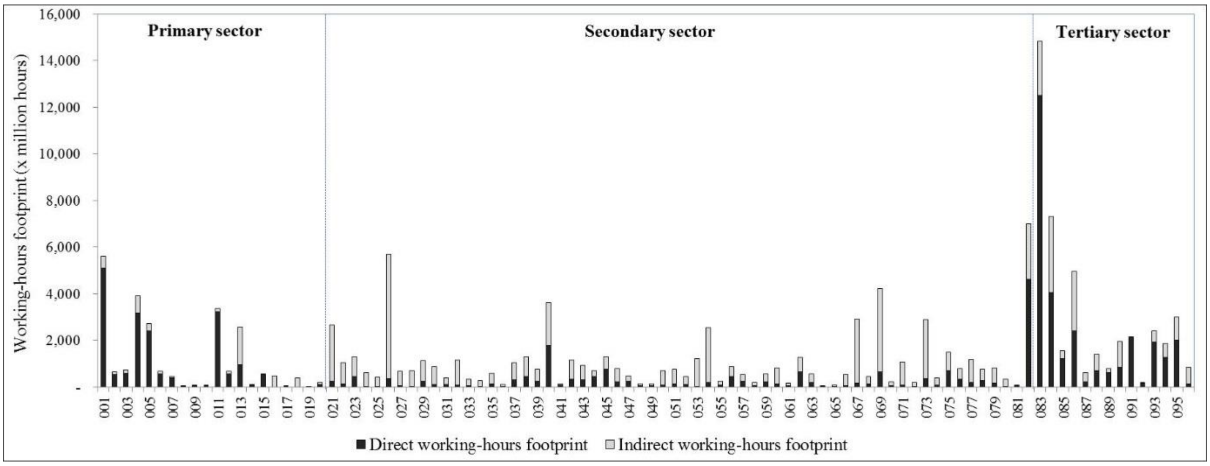

Figure 4-6. Working-hours footprint of Thailand by economic sector using the 2005 Thailand input-output table.

4.3.3 Wages

4.3.3.1 Wages intensity

The IO table gives the data on the average wages paid to employees. In each sector, the average wages of employees are different. Pay in each economic sector shows the amount of earnings that are directly required to produce one unit of production of that sector. Wages are a part of the production cost in each sector. Thus, if a component of the production of any sector is used as an input for production of other sectors, its increased price affects the production cost in other sectors as well.

The total wages intensity from 96 industrial sectors is given in Figure 4-7. The largest wages intensity is public administration sector accounting for 0.92 million Thai Baht/million Thai Baht output. The highest intensity in the public administration sector was due to this sector accounting for only labor compensation and depreciation but it does not have input from others sectors. The next was education and research (0.72) followed by sanitary and similar services (0.62), maize and other grain (0.54), forestry (0.49), medical (0.46), cassava (0.44), and sugarcane (0.43), respectively. The result shows that almost all the primary and service sectors have greater direct wage intensity whereas the secondary sector had a higher share of indirect wages intensity. This is due to Thailand being categorized as a middle-income country, with an intermediate level of production technology. The key industries in the manufacturing sector use low wages as a base for competitive advantage. Thus, the secondary sector had a lower share of direct wage intensity.

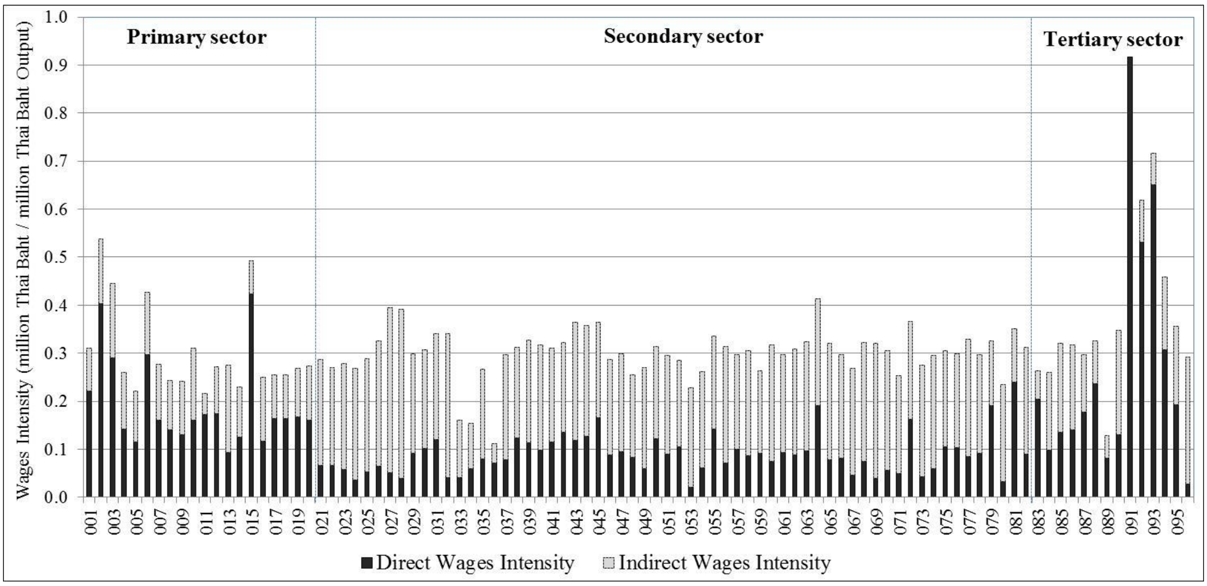

Figure 4-7. Wages intensity of Thailand by economic sector using the 2005 Thailand input-output table.

4.3.3.2 Wages footprint

Figure 4-8 shows the results of the total remuneration paid to employees or wages footprint for each economic sector. From wages intensity, the ranking changes, and the most important wages intensive sector becomes the wholesale and retail trade sector (579,949 million Thai Baht), followed by transportation (305,861 million Thai Baht), public administration (298,720 million Thai Baht), education and research (247,547 million Thai Baht), motor vehicle (202,985 million Thai Baht), construction (201,219 million Thai Baht), and petroleum refineries sector (201,174 million Thai Baht), respectively. This change may be explained by the high final demand of the wholesale and retail trade, transportation, petroleum refinery, motor vehicle, and construction sectors that indicate a smaller wages intensity. Also, the small final demand of public administration and education sector imply a bigger wages intensity. The bigger indirect wages are in petroleum refineries, motor vehicle, industrial electrical machinery, radio and television, and transportation sectors due to the effect from raw material inputs in these sectors.

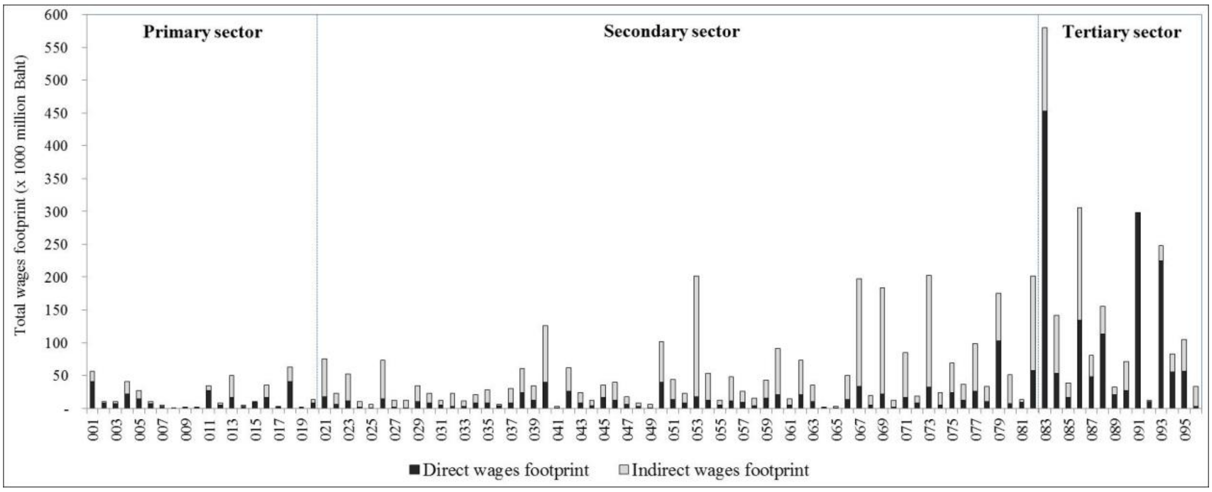

Figure 4-8. Wages footprint of Thailand by economic sector using the 2005 Thailand input-output table.

4.3.4 Non-fatal occupational injury

4.3.4.1 Non-fatal occupational injury intensity

Figure 4-9 shows the non-fatal occupational injury intensity of 96 industrial sectors in 2005. The highest non-fatal occupational injury intensity is the metal product sector (3.78E-02 cases/million Thai Baht output) follow by saw mills (3.49E-02 cases/million Thai Baht output), wood furniture (3.42E-02 cases/million Thai Baht output), home appliances (3.25E-02 cases/million Thai Baht output), basic metal (2.35E-02 cases/million Thai Baht output), household machinery (2.03E-02 cases/million Thai Baht output), plastic products (1.98E-02 cases/million Thai Baht output), printing and publishing (1.93E-02 cases/million Thai Baht output), construction (1.68E-02 cases/million Thai Baht output), and motor vehicle sector (1.59E-02 cases/million Thai Baht output), respectively.

The non-fatal occupational injury intensity in the metal product, basic metal, household machinery, plastic products, construction, and motor vehicle sector were more severe than other sectors due to these sectors being high risk work activities. While, timber, wood furniture, home appliances, and printing and publishing sectors are high risk work activities and with low economic value. However, the improvement in occupational safety in these sectors over time is also obvious; the non-fatal accident cases in these sectors decreased from 2005–2010 by 30%–50%. There are only 20 economic sectors in which the direct non-fatal occupational injury intensity is larger than the indirect effect; including agricultural service, forestry, lignite mining, metallic mining, non-metallic mining, spinning and weaving, dyeing, saw mills, wood furniture, printing and publishing, rubber and tries, plastic products, metal products, home appliances, wholesale and retail trades, real-estate, business services, and sanitary and similar services sectors.

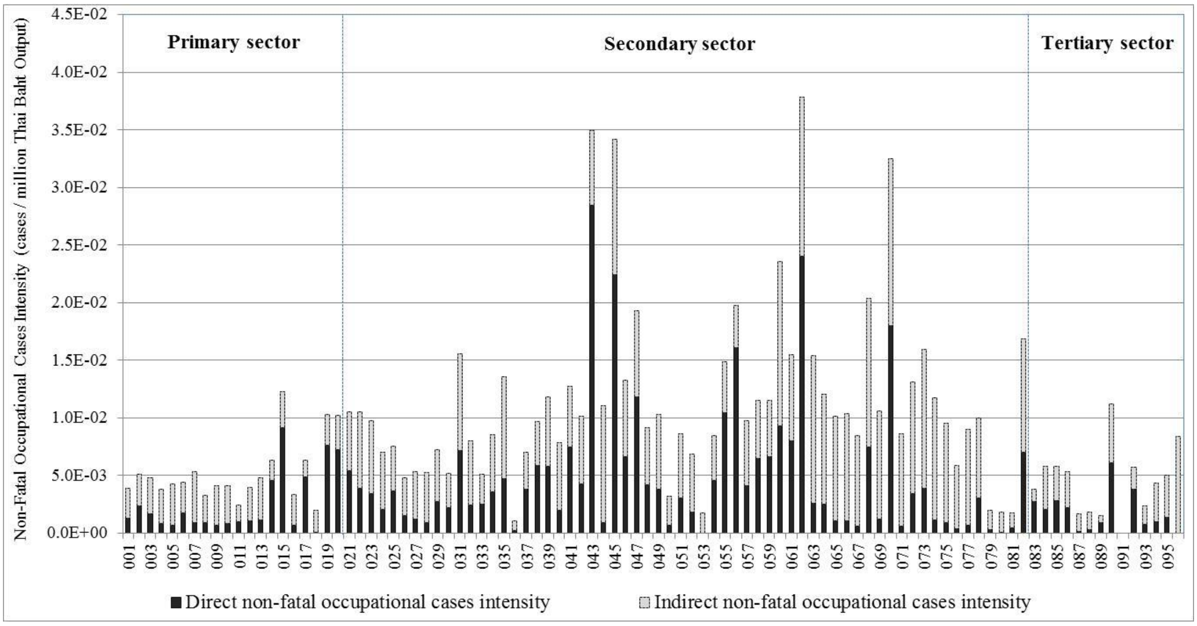

Figure 4-9. Non-fatal occupational cases intensity of Thailand by economic sector using the 2005 Thailand input-output table.

Data on incidents, including fatal injuries, are published by the Social Security Office of Thailand (SSO) focusing on the incidents in formal labor of the private sector under the Thai Social Security Act. There are no reports on non-fatal injury and fatality cases in government agencies and informal labor in the private sector [37].

4.3.4.2 Non-fatal occupational injury footprint

Figure 4-10 shows the result of the non-fatal occupational injury footprint for each economic sector. From non-fatal occupational injury intensity, the ranking changes, and the most important non-fatal occupational injury intensive sector becomes the motor vehicle sector (direct 2,881 and total 11,744 cases), followed by construction (direct 4,501 and total 10,851 cases), metal products (direct 5,701 and total 8,966 cases), wholesale and retail trade (direct 4,501 and total 8,468 cases), iron and steel (direct 2,676 and total 6,748 cases), electrical industrial machinery (direct 440 and total 6,201 cases), radio and television (direct 668 and total 6,039 cases), transportation (direct 2,142 and total 5,157 cases), and wood furniture (direct 2,216 and total 3,378 cases), respectively. This change may be explained by the high final demand of the wholesale and retail trade and transportation sectors that indicates the smaller non-fatal occupational injury intensity of these sectors. At the same time, the small final demand of the electrical industrial machinery and wood furniture sectors indicate bigger non-fatal occupational injury intensity. The bigger indirect non-fatal occupational injury intensity is the motor vehicle, electrical industrial machinery, radios and television, and construction sector is due to the effect from raw material inputs in these sectors.

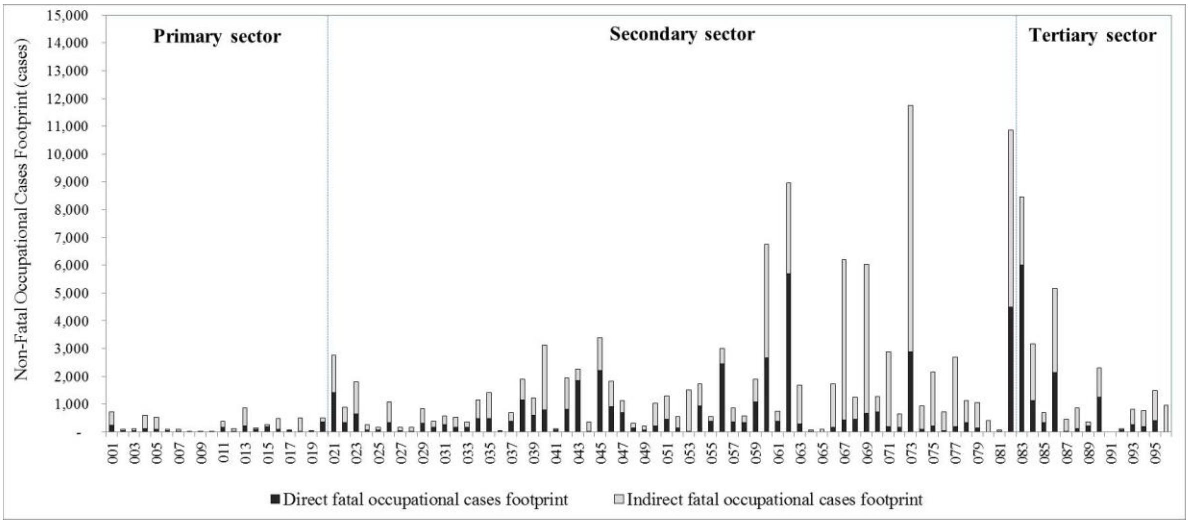

Figure 4-10. Non-fatal occupational cases footprint of Thailand by economic sector using the 2005 Thailand input-output table.

Statistical data from the Social Security Office, Ministry of Labour reported that 7.99 million (22.5%) workers registered with the Social Security Office. The following occupational accident statistics in 2005 are only for insured workers. Occupational accident statistics are gathered from the Office of Workmen's Compensation Fund (WCF), Social Security Office (SSO) under Ministry of Labour (SSO, 2006). The first cause of occupational accidents are cuts or stabbings by materials or objects, the second cause is impact by materials or objects, the third cause is materials or objects or chemical substances getting into eyes, and the fourth cause is materials or objects collapsing. In addition, the highest number of occupational accident cases are workers aged between 25 and 29 years followed by those 20–24 years old, and 30–34 years old, respectively. The occupational accident cases classified by sector showed that the highest occupational accident cases are manufacturing of metal products followed by commercial establishments, and construction, respectively (Ministry of Labour, 2012).

4.3.5 Fatal occupational injury

4.3.5.1 Fatal occupational injury intensity

Figure 4-11 shows the fatal occupational injury intensity of 96 industrial sectors in 2005. The highest fatal occupational injury intensity is the non-metallic mining sector (4.00E-04 cases/million Thai Baht output) followed by fertilizer and pesticides (3.63E-04 cases/million Thai Baht output), construction (3.42E-04 cases/million Thai Baht output), business services (2.81E-04 cases/million Thai Baht output), saw mills (3.38E-04 cases/million Thai Baht output), cement and concrete (2.37E-04 cases/million Thai Baht output), household machinery (2.05E-04 cases/million Thai Baht output), metal products (1.89E-04 cases/million Thai Baht output), forestry (1.68E-04 cases/million Thai Baht output), and printing and publishing sectors (1.71E-04 cases/million Thai Baht output), respectively.

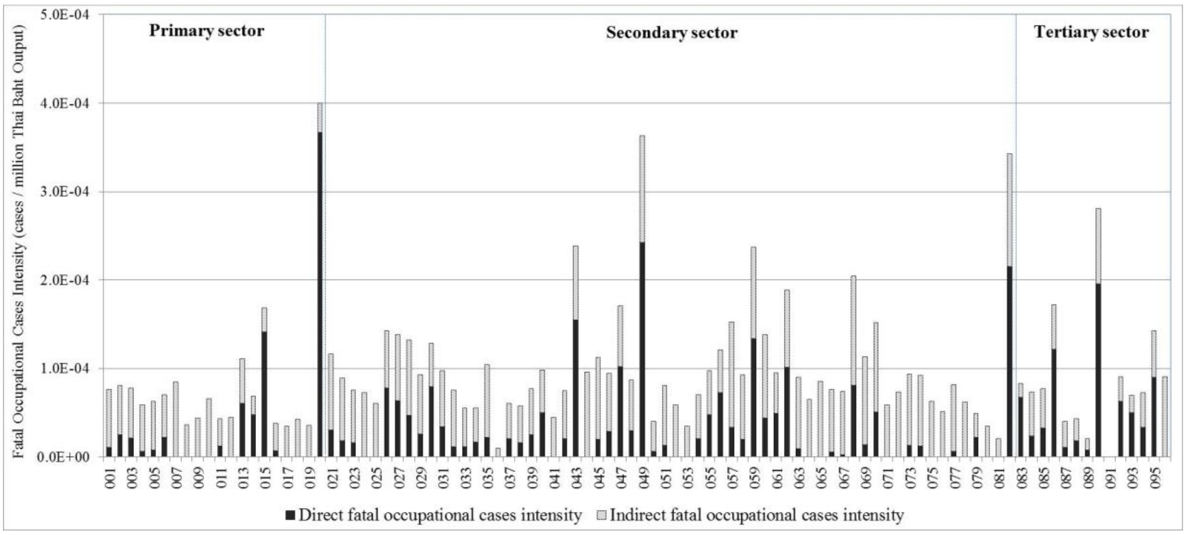

Figure 4-11. Fatal occupational cases intensity of Thailand by economic sector using the 2005 Thailand input-output table.

The fatal occupational injury intensity in the construction sector was more than other sectors. This is mainly because this sector is labor-intensive and involves high-risk work activities. In addition, numbers of deaths per 1000 workers in the construction sector are higher than that of other sectors (Ministry of Labour, 2012). However, the improvement in occupational safety in this sector over time is also obvious; the numbers of fatal accident cases in this sector decreased from 2005–2010, estimated at 38%. The fatal occupational injury intensity in the non-metallic mining, fertilizer and pesticides, and saw mill sectors was more than other sectors due to high-risk work activities and low economic value.

4.3.5.2 Fatal occupational injury footprint

The result of the fatal occupational injury footprint for each economic sector is shown in Figure 4-12. From the fatal occupational injury intensity, the ranking changes, and the most important fatal occupational injury intensive sector becomes the construction sector (direct 139 and total 221 cases), followed by wholesale and retail trade (direct 149 and total 184 cases), transportation (direct 117 and total 166 cases), motor vehicle (direct 10 and total 69 cases), and radio and television sectors (direct 8 and total 65 cases), respectively. This change may be explained by the high final demand of the wholesale and retail trade, motor vehicle, and radio and television sectors that indicates the smaller fatal accident case intensity of this sector. For the construction sector, both final demand and fatal occupational injury intensity has a high value. The larger number of indirect fatal occupational injury cases are in motor vehicle, radio and television, and electrical industrial machinery sectors due to the effect from raw material inputs in these sectors.

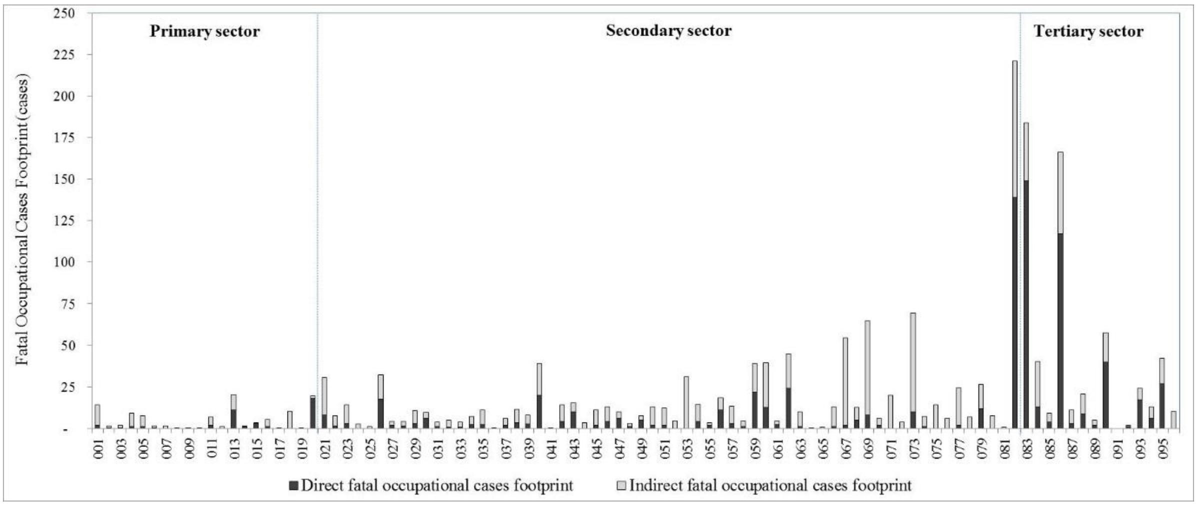

Figure 4-12. Fatal occupational cases footprint of Thailand by economic sector using the 2005 Thailand input-output table.

4.4 Discussions

The labor intensity is calculated by the ratio of employment to monetary output of each economic sector. When comparing industries that are capital-intensive and labor-intensive, the labor intensity of labor-intensive industries will use a greater number of workers or working hours for the same level of output. Based on the direct labor intensity and direct working hour intensity, economic sectors that are labor intensive include agricultural, fishery, wholesale and retail trades, construction, garment, leather, and furniture while economic sectors that are not labor-intensive such as automotive, refinery and petrochemical will be able to deal with the higher wage with fewer burdens. Previous studies (Xu *et al.*, 2010; Garrett-Peltier, 2010; Gomez-Paredes *et al.*, 2015) have shown that agricultural, construction, textiles, and wood product sectors were labor-intensive especially in developing countries such as China and India which is a similar result to our study. In addition, the service sectors were found to be labour intensive too, and this result is consistent with other studies (Garrett-Peltier, 2010; Simas *et al.*, 2014).

According to statistical data of Thailand (NSO, 2006), the agricultural, forestry, and fishery sectors directly employed 13.27 million workers while the service sector employed 16.05 million and the remainder of workers were found in the manufacturing sector (5.86 million). The main concentration of employment is in the service sector, followed by the agricultural sector. It should be noted that employment in the agricultural sector has dropped continuously while employment in the service sector has increased, with female workers shifting away from the agricultural sector into the service sector. Despite high employment in the agricultural sector, labor productivity in this sector is still at a low level. In 2005, GDP of the agricultural sector accounted for just 10.27% while GDP of the manufacturing and service sectors accounted for 40.95% and 48.79%, respectively (NESDB, 2015). According to Thailand's statistics, employment is divided into five groups including salary workers (42.4%), employers (3%), self-employed workers (31.5%), unpaid family workers (23%), and co-operative workers (0.1%). It should be noted that the weak employment rate of Thailand is high as 55% of total employment consists of self-employed workers and unpaid family workers.

For wage intensity, almost all the primary and service sector has higher direct wage intensity than that of the secondary sector, due to Thailand being categorized as a middle-income country and having an intermediate level of production technology. A key strategy of the manufacturing sector is the use of low wages for maintaining competitiveness advantage. Thus, the secondary sector had a lower share of direct wage intensity than other sectors. In addition, due to the high proportion of self-employed workers and unpaid family workers in Thailand, these worker groups were excluded for measuring wage intensity.

According to the report on occupational safety and health in Thailand (Ministry of Labour, 2012), it was found that statistical relationships between socio-demographic variables and incidents of occupational injury depend on sex, age, job experience, and occupation. This study shows a higher possibility of fatality for workers in the construction, wholesale and retail trades, transportation, and motor vehicle sectors. Overall, 10 years ago, the construction sector reported the highest fatality rate in Thailand. The work-related injuries rate per 1000 workers in the construction sector was twice as high as the overall industry rate (SSO, 2010). These results are compatible with other studies of the construction sector (Onat *et al.*, 2012; Gonzalez-Delgado *et al.*, 2015) and services sector (Waehrer *et al.*, 2005). In addition, it found that male workers illustrated a higher risk of fatality from an occupational injury, which may be explained by their jobs having a higher level of exposure to risks than female's jobs. Non-fatal occupational injury appeared to be most concentrated in the motor vehicles, construction, metal products, and wholesale and retail trade sectors. The results of our study are similar to other studies such as construction (Onat *et al.*, 2012; Simas *et al.*, 2014), metal products (Kifle *et al.*, 2014) and service sector (Waehrer *et al.*, 2005; Simas *et al.*, 2014). In case of the motor vehicle sector, non-fatal injury cases are significantly higher in indirect cases than other industries, with a ratio of 3 times. This high ratio means that great care is taken to shield worker health and safety in this sector, whereas supply sectors are notably dangerous, especially the iron and steel and metal products sectors. In addition, the rate of occupational injuries per 1000 workers was highest in the aged group of 15–19 year old followed by the 20–24 year old group and 25–29 year old group, respectively (SSO, 2006). The young workers are at higher risk of occupational injuries due to being experienced in their jobs. In terms of the specific occupation, the workers in the construction sector, machine operators and technicians in the manufacturing sector, and salespeople in wholesale and retail trade sectors show higher possibilities of non-fatal occupational injury. The high risk of occupational injuries in construction, manufacturing, and service sectors may be related to a lack of training for the duties and a lack of access to safety standards on the job, and could also be attributed to educational level.

4.4.1 Policy implications

Social footprint indicator based on IOA framework related to commodities can provide guidance on where to focus in investigation and implementation strategies. For example, endeavors to address labor issues in the production of agricultural products (such as paddy, cassava, sugarcane, maize, fruits, vegetables, *etc.*) and fishery products should focus on direct employment as indirect labor is less important. For the construction, wood and cork products, wood furniture, and restaurant sectors, both direct and indirect employment become important, particularly concerning female employment and working hours.

4.4.2 Supply chain implications

On the contrary, social issues linked to the electrical and electronics industry (such as electrical appliances, radio and television, and battery, cable and lighting) and motor vehicles sector (Figures 4-9 and 4-11), supply chain controls are the most important. Possibly, approaches to solving social issues should focus on the most directly affected sectors. Addressing issues in these sectors (Figure 4-9) will mitigate not only their sectors' footprints, but also those sectors' inputs. For example, reducing non-fatal occupational injury in the iron and steel and metal products sectors will lower the indirect non-fatal injury in the motor vehicles, and electrical and electronics industries.

4.4.3 Consumer implications

By considering the share of social footprint in traded goods, we found that more than 50% of each social footprint in the top 10 economic sectors is from domestic consumption. Except for the radio and television, electrical industrial machinery, and rubber products and tubes sectors, the export share makes for a significant part of these sectors (range from 65%–96%). In addition, we found that the primary and tertiary sectors has a significant share of its social footprint in domestic consumption, accounting for 60%–100%. While in the secondary sectors, more than 30% of social footprints in these sectors are mainly driven by foreign consumption, whereas the rest is the production for use domestically. We can conclude that the share of exports' social footprint is higher in secondary sectors than in other sectors. The main exports of Thailand are electrical and electronics appliances, wearing apparels, rubber products, and motor vehicles. The manufacturing of these products may require direct labor from the domestic market. Investigating the main social footprint flows in export products of Thailand shows that underlying social issues virtually flow from Thailand to foreign countries.

4.4.4 Limitation of this study

Socially extended input–output model allows following the flow of social footprints along supply chains. By considering social aspects in every production step, the result is a social inventory of production and consumption, e.g., employment, female employment, fatal and non-fatal occupational injury footprints of sectors or countries. Social footprint based on IO model is served by data that are assembled at the sector level rather than for specific products.

Input–output tables are the sum of financial transactions of very many individual activities and are grouped into a limited number of industries. An IOA shows the social impact of an industry or product group (e.g., soft drink products) but not of a specific product (e.g., orange juice). In addition, the social footprint based on IO approach has some limitations; examining labor issues via IOA gives only a historical picture linked to given economic activities in the considered time period. However, labor dimensions might not imitate the linear proportion assumption. For example, if the demand for a commodity and its wage footprint is reduced, it would be incorrect to assume that wage rate will be reduced also. Actually, it is possible that less profit may be a stimulant for some employers to move to lessen their costs. When considering the social footprint based on input–output analysis, it is estimated that 57% of the Thai labor force work in the informal market. This is not included within the non-fatal and fatal footprint of this work. These values will be captured at the point in the supply chain where the good or service is sold or purchased in the formal economy. The lack of data on the sub-sector share of labor in the agricultural sector results in large uncertainty in this analysis. In addition, this study did not consider imports' effect in its calculations. Further work on this analysis is recommended including the impacts from importing of raw materials.

4.4.5 Sensitivity analysis

In order to evaluate the impact of changes of system boundary on the employment intensity of Thailand, taking into consideration the sensitivity analysis were carried out as follows:

- Base case scenario (THIO-included import): evaluate the employment intensity using the THIO table by including the effects from import.
- Scenario 1 (THIO-excluded import): evaluate the employment intensity using the THIO table by excluding the effects from import.

The results of the sensitivity analysis done for two scenarios effect on the employment intensity of Thailand are shown in Figure 4-13 to Figure 4-16. This result presented as percentages relative to the base case scenario (THIO-included import). It can be confirmed that the import effect shows the high significant impact on the employment intensity in most sectors of the manufacturing sector, particularly in the economy sector that rely on raw materials from other countries. While the agricultural sector and service sector are less significant impact due to those are used most of the raw materials within the country.

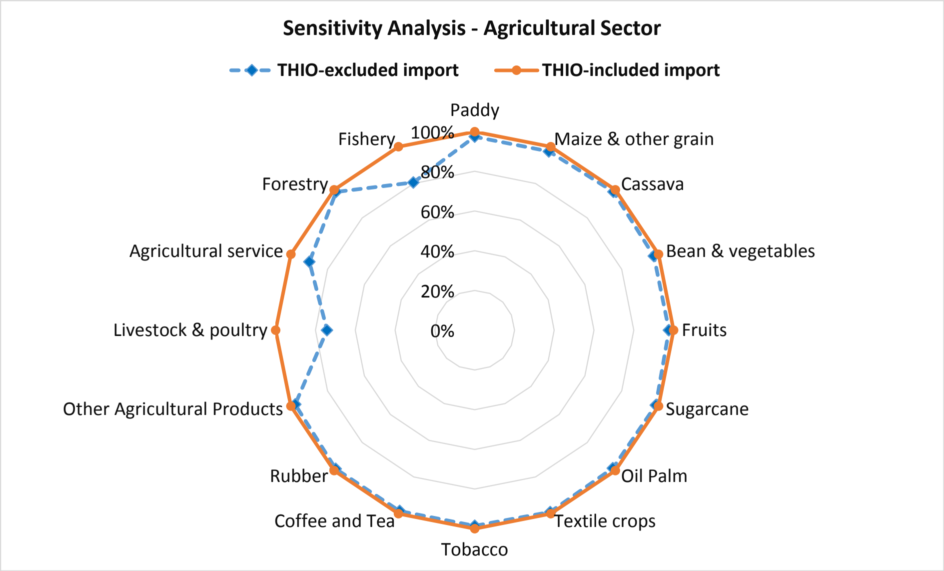

Figure 4-13. Sensitivity analysis of the employment intensity in agricultural sector.

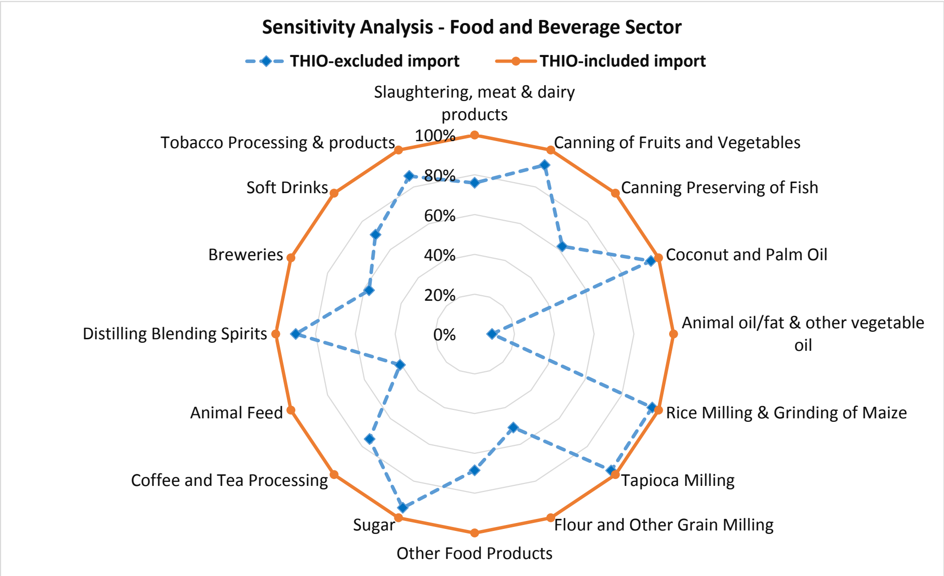

Figure 4-14. Sensitivity analysis of the employment intensity in food and beverage sectors.

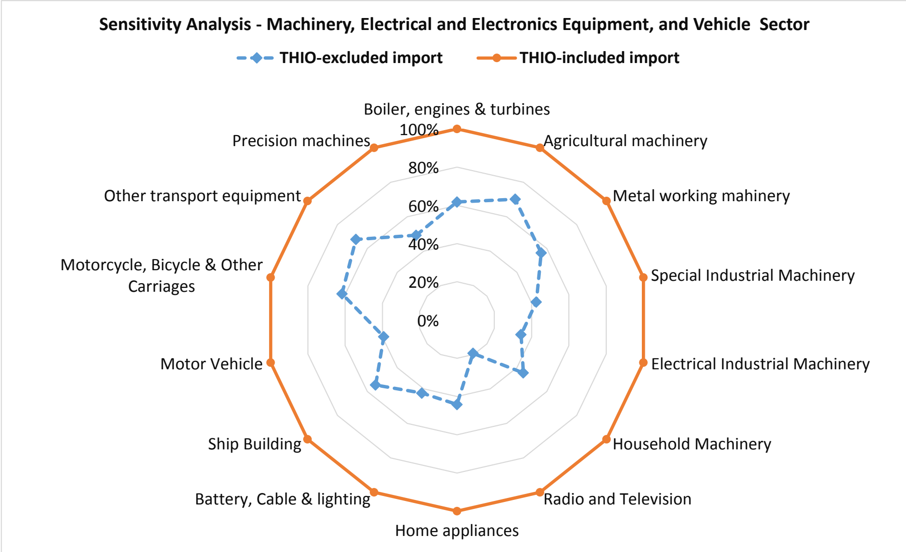

Figure 4-15. Sensitivity analysis of the employment intensity in machinery, electrical and electronics equipment, and vehicle sectors.

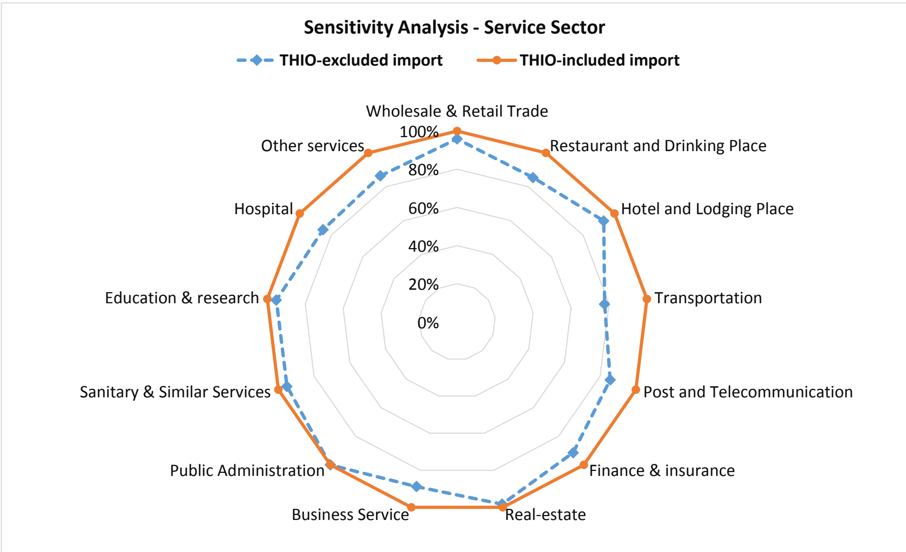

Figure 4-16. Sensitivity analysis of the employment intensity in service sector.

4.5 Conclusions

- This study calculates the direct and indirect social footprint associated with the activities of the Thai economy and detects key sectors and important social issues in Thailand using the IO model. The five different social issues are calculated including employment, working hours, wages, non-fatal occupational injury, and fatal occupational injury. The results show that the primary sector has the highest social intensity in terms of employment, female employment, and working hour intensity. Meanwhile, the secondary sector was higher in non-fatal occupational cases' intensity than other sectors. The government sector was higher in wages intensity than other sectors due to being labor intensive and of low economic value. In addition, the fatal occupational cases intensity was highest in the non-metallic mining, fertilizer and pesticides, and construction sectors.

- We calculated the expected increase in social impacts throughout the entire supply chain, from minerals extraction to energy supply, components production, and final assembly. This study provides information for companies and consumers regarding the social issues associated with their purchases. If businesses and consumers become more concerned about the social implications of their activities, they may incentivize the supply chain to perform better. For example, for social issues linked to the electrical and electronics industry, and the motor vehicles sector, supply chain controls are the most important. Reduction of non-fatal occupational injury in the iron and steel, and metal products sectors will lower the indirect non-fatal injury of motor vehicle sectors, and electrical and electronics industries. Thus, producers can force their suppliers to reduce the social footprint of their products.
- Although the IO model presented in this study is easy to use, it has some limitations that should be considered. Some debatable issues include calculations based on the linear inter-industry interactions, the estimations at national level, data availability and data quality. The aggregation of data used for calculations may lead to under/over estimations, such as accident cases within the agricultural sector are allocated based on economic value. In addition, this study did not consider imports in its estimations.
- It is not easy to quantify all social issues and all sectors of sensitivity analysis in the database. However, in the sensitivity analysis of manufacturing sector focused on the change in the system boundary seem to be important to influence on the employment intensity accounting in most sectors. Furthermore, polishing of direct employment intensity in the manufacturing sector of the import from other countries may increase the precision of employment intensity database since the direct employment intensity from other countries is a critical point in the employment footprint database establishment of Thailand.

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Chapter 5. Development of Social Inventory Database using Asian International Input-Output Table

5.1 Introduction

Life Cycle Assessment (LCA) is a helpful tool for evaluating and quantifying the environmental consequences relevant to a product, process, or service from the cradle to the grave in a systematic approach (ISO, 2006) [1]. In addition, the social dimension can be included in the LCA method to evaluate the social impacts of a product, the so-called social LCA (S-LCA). The results of an S-LCA is provide information on social performance to be communicated with stakeholders. The Products S-LCA Guidelines of UNEP/SETAC is a popular manual for many S-LCA studies around the world [2]. Almost all social issues addressed in the S-LCA case studies evaluated social impact in terms of a qualitative and semi-quantitative approach. In this regard, there is a lack of quantitative inventory data for many social indicators.

The S-LCA guidelines of UNEP/SETAC proposed social indicators in terms of quantitative, qualitative and semi-quantitative factors. The social inventory issues in this guideline consist of five stakeholder groups: workers, local communities, consumers, society, and value chain actors [2]. There have been many S-LCA studies around the world and many social issues evaluated based on the International Labour Organization's (ILO) perspective. There are many S-LCA frameworks that have been proposed. Dreyer et al. [3] offered the S-LCA framework by focusing on international criteria and company relevance. Hutchins et al. [4] proposed a framework for characterizing and identifying key characteristics of the social impacts of products or processes using a process-based LCA approach. The development and application of the social hotspots database (SHDB) were demonstrated by Benoit-Norris et al. [5]. This SHDB was developed by following the S-LCA Guidelines of UNEP/SETAC. Information on the social indicators of 191 countries with multiple sectors is presented in the SHDB. The data were collected from over 200 data sources, mostly international organizations' databases.

There are many S-LCA studies using an input–output analysis (IOA) framework. However, connecting social issues with the input–output database using satellite accounts is insufficient. Social impacts such as employment, working hours, labor conditions, or occupational health can be assessed using the IOA method. Almost all case studies are focused on only an employment issue (Garrett-Peltier [6]; Martinez et al. [7]; Chen et al. [8]; Tang et al. [9]; Lee and Yoo [10]; Ferrao et al. [11]; McBain and Alsamawi [12] Malik et al. [13]; Yang et al. [14]).

The case studies conducted by Kucukvar et al. [15] are interested in income and work-related injuries, and Alsamawi et al. [16] focused on the employment and income footprint. Chang [17] evaluated the social impacts in terms of the accidents, fatalities, employment, research and development personnel, science and technology (ST) personnel, and funding for ST activities of a construction project. Onat et al. [18] assessed the social impacts on income, government tax, and injuries of the building sector. Simas et al. [19] assessed social impacts in term of bad labor footprints consisting of indices such as negative impacts on occupational health, vulnerable employment, gender inequality, unskilled workers, child labor, and forced labor. Whereas, Gómez-Paredes et al. [20] focused on six labor issues including collective bargaining, child labor, forced labor, gender inequality, hazardous work, and social security. Papong et al. [21] established the social inventory dataset of Thailand using an IOA approach, in which social issues covered the total employment, female employment, worked hours, wages and salaries, fatal, and non-fatal injuries.

This study aimed to establish a social intensity database using the IOA framework, covering 10 Asian countries, for the year 2005. The IOA framework is an analytical tool for evaluating impacts along with the production chains of economic systems referred to as "footprints". This framework can be estimated through an environmentally extended IOA. The Asian International Input–Output (AIIO) database was used as the basis for this study. The social satellite accounts were developed using data on total employment, paid workers, vulnerable employment, wages, and fatal and non-fatal injuries to construct the social inventory dataset. Using the Leontief Inverse Matrix to calculate the AIIO table with associated satellite accounts, the resulting data shows the social intensities for 10 countries covering the output of 760 economic sectors. By multiplying this with the final consumption of each country, the result shows the social footprints require from domestic products and services and that imported from overseas, to fulfil the final demand of each country.

5.2 Materials and methods

This section describes the methods applied in the study. The definitions of the social footprint indicators used are descriptions as presented in Table 5-1. We calculated the social inventory database in terms of social intensities associated with final consumption. We used a consumption-based approach to estimate the social footprint and. different indicators of social intensities were compared to give a coherent impact of the consumed products.

5.2.1 Social footprint indicators

5.2.1.1 Total employment

Total employment in this study covers all status groups, which consists of salaried employees, paid family workers, employers, the self-employed, members of cooperatives, unpaid family workers and workers not classifiable [22]. There are no differences between persons who worked full-time and part-time. The unit of measurement is the number of persons in employment.

5.2.1.2 Paid worker

A paid worker is a person who works for a public or private employer and receives compensation in wages, commission, tips, piece-rates or pay in kind. This comprises full-time workers, part-time workers, home-based workers, fixed-term workers, seasonal workers, and employees on probationary and trial periods [22]. The measured unit is the number of persons in total labor with employee status.

5.2.1.3 Vulnerable employment

Workers considered as in vulnerable employment are defined as the sum of the employment status groups of self-employed and unpaid family workers. This worker group has no formal employment agreement [23]. Therefore, they are likely to lack decent working conditions. This may include the following: workers not covered by social security and labor regulations; labor without contribution to and advantages from retirement schemes; workers with no constancy and security of work, etc. In developed countries, vulnerable employment contributes to 10% of the total workforce, whereas in the developing countries they account for nearly three-quarters of total workers [24]. The measured unit is the number of persons in total labor without employee status.

5.2.1.4 Wages

Wages refer to the amount of money agreed between an employer and an employee to be paid in return for work done under a contract of employment for normal working periods (such as hourly, daily, weekly, monthly or other period of time basis), or on the basis of piecework done during the normal working time of a working day. It also includes money to be paid by an employer to an employee on holiday and on leave during which the employee does not work but is entitled to the money under the labor regulation [22]. Employees are classified as long-term workers, temporary workers, executives and hired laborers in the agricultural sector, but excluded family workers. The measured unit is the amount of money (USD) that the employer paid to the employee.

5.2.1.5 Fatal occupational injury

The fatal occupational injury is injuries that led to death within a year of the day of the occupational accident. The occupational accident is an unexpected and unplanned event, including acts of violence, occurring out of or relation to work which effects one or more workers suffering a personal injury, disease or death [22]. The indicator used to evaluate the fatal occupational injury is the number of cases of death caused by the occupational accidents during one year.

5.2.1.6 Non-fatal occupational injuries

Non-fatal occupational injuries are cases of occupational injury where the injured workers are unable to work temporarily or permanently after that. Cases of temporary disability are cases of occupational injury where the workers injured were incapable of working after the accident, but assumed normal duties of work within one year from the day of the accident [22]. The indicator used to evaluate the non-fatal occupational injury is the number of cases of injury caused by the occupational accidents during one year.

Table 5-1. Summary of labor footprint indicators used in the study.

Measure	Indicators	Unit	Definition	Data Source	Data Year
Employment	Total employment	Persons-year	Total employment needed for producing goods and services	[26]	2005
Paid worker	Persons in total labor with employee status	Persons-year	Persons who works for a public or private employer and receives compensation in wages, salary, commission, tips, piece-rates or pay in kind.	[26]	2005
Vulnerable employment	Persons in total labor without employee status	Persons-year	Workers who are the employment status groups of self-employed and unpaid family workers.	[26]	2005
Wages	Income	Million US Dollar	The compensation by employers to employees. Employees are classified as long-term workers, temporary workers, executives and hired laborers in the agricultural sector, but excluded family workers.	[27]	2005

Fatal occupational cases	Fatal cases in workplace	Cases-year	Cases where workers were fatality injured as a result of occupational accidents, and where death occurred within one year of the day of the accident.	[28-40]	2005
Non-fatal occupational cases	Non-fatal cases in workplace	Cases-year	Cases of occupational injury where the workers injured were unable to work temporarily or permanently from the day after the day of the accident.	[28-40]	2005

5.2.2 Input – output model

The economic input–output model was developed by Leontief [25] and is generally used as a quantitative model for analysis of the national and regional economic impact. The input–output analysis (IOA) can analyze flows of products and services between economic sectors and final demand. Social and environmental footprints embodied in products and services can be calculated using the IOA framework by applying a socially and environmentally extended input–output table for evaluating the impacts of each economic sector. The strength of the IOA model is having a comprehensive system boundary, consistent results, and cost and time savings [26]. However, the limitations of IOA are that it provides only a rough analysis for specific products, and is highly dependent on information availability. The social footprints of intra-trade and inter-trade were calculated using the Asian International Input-Output (AIIO) model. The model overviews the 2005 Asian economy and consists of 76 industrial sectors traded within and among 10 countries [26]. In this study, we divided Asian countries into three categories: (1) developed countries (the US and Japan); (2) richest Asian countries (South Korea, Taiwan, and Singapore); and (3) developing countries (China, Malaysia, Thailand, Indonesia, and Philippines). The layout of the 2005 Asian international input-output table is shown in Figure 5-1.

	code	Intermediate Demand (A)										Final Demand (F)										Export (L)				
		Indonesia (AI)	Malaysia (AM)	Philippines (AP)	Singapore (AS)	Thailand (AT)	China (AC)	Taiwan (AN)	Korea (AK)	Japan (AJ)	U.S.A. (AU)	Indonesia (FI)	Malaysia (FM)	Philippines (FP)	Singapore (FS)	Thailand (FT)	China (FC)	Taiwan (FN)	Korea (FK)	Japan (FJ)	U.S.A. (FU)	Export to H.Kong (LH)	Export to EU (LO)	Export to R.O.W. (LW)	Discrepancy (QX)	Total Outputs (XX)
Indonesia	(AI)	A^{II}	A^{IM}	A^{IP}	A^{IS}	A^{IT}	A^{IC}	A^{IN}	A^{IK}	A^{IJ}	A^{IU}	F^{II}	F^{IM}	F^{IP}	F^{IS}	F^{IT}	F^{IC}	F^{IN}	F^{IK}	F^{IJ}	F^{IU}	L^{IH}	L^{IO}	L^{IW}	Q^{I}	X^{I}
Malaysia	(AM)	A^{MI}	A^{MM}	A^{MP}	A^{MS}	A^{MT}	A^{MC}	A^{MN}	A^{MK}	A^{MJ}	A^{MU}	F^{MI}	F^{MM}	F^{MP}	F^{MS}	F^{MT}	F^{MC}	F^{MN}	F^{MK}	F^{MJ}	F^{MU}	L^{MH}	L^{MO}	L^{MW}	Q^{M}	X^{M}
Philippines	(AP)	A^{PI}	A^{PM}	A^{PP}	A^{PS}	A^{PT}	A^{PC}	A^{PN}	A^{PK}	A^{PJ}	A^{PU}	F^{PI}	F^{PM}	F^{PP}	F^{PS}	F^{PT}	F^{PC}	F^{PN}	F^{PK}	F^{PJ}	F^{PU}	L^{PH}	L^{PO}	L^{PW}	Q^{P}	X^{P}
Singapore	(AS)	A^{SI}	A^{SM}	A^{SP}	A^{SS}	A^{ST}	A^{SC}	A^{SN}	A^{SK}	A^{SJ}	A^{SU}	F^{SI}	F^{SM}	F^{SP}	F^{SS}	F^{ST}	F^{SC}	F^{SN}	F^{SK}	F^{SJ}	F^{SU}	L^{SH}	L^{SO}	L^{SW}	Q^{S}	X^{S}
Thailand	(AT)	A^{TI}	A^{TM}	A^{TP}	A^{TS}	A^{TT}	A^{TC}	A^{TN}	A^{TK}	A^{TJ}	A^{TU}	F^{TI}	F^{TM}	F^{TP}	F^{TS}	F^{TT}	F^{TC}	F^{TN}	F^{TK}	F^{TJ}	F^{TU}	L^{TH}	L^{TO}	L^{TW}	Q^{T}	X^{T}
China	(AC)	A^{CI}	A^{CM}	A^{CP}	A^{CS}	A^{CT}	A^{CC}	A^{CN}	A^{CK}	A^{CJ}	A^{CU}	F^{CI}	F^{CM}	F^{CP}	F^{CS}	F^{CT}	F^{CC}	F^{CN}	F^{CK}	F^{CJ}	F^{CU}	L^{CH}	L^{CO}	L^{CW}	Q^{C}	X^{C}
Taiwan	(AN)	A^{NI}	A^{NM}	A^{NP}	A^{NS}	A^{NT}	A^{NC}	A^{NN}	A^{NK}	A^{NJ}	A^{NU}	F^{NI}	F^{NM}	F^{NP}	F^{NS}	F^{NT}	F^{NC}	F^{NN}	F^{NK}	F^{NJ}	F^{NU}	L^{NH}	L^{NO}	L^{NW}	Q^{N}	X^{N}
Korea	(AK)	A^{KI}	A^{KM}	A^{KP}	A^{KS}	A^{KT}	A^{KC}	A^{KN}	A^{KK}	A^{KJ}	A^{KU}	F^{KI}	F^{KM}	F^{KP}	F^{KS}	F^{KT}	F^{KC}	F^{KN}	F^{KK}	F^{KJ}	F^{KU}	L^{KH}	L^{KO}	L^{KW}	Q^{K}	X^{K}
Japan	(AJ)	A^{JI}	A^{JM}	A^{JP}	A^{JS}	A^{JT}	A^{JC}	A^{JN}	A^{JK}	A^{JJ}	A^{JU}	F^{JI}	F^{JM}	F^{JP}	F^{JS}	F^{JT}	F^{JC}	F^{JN}	F^{JK}	F^{JJ}	F^{JU}	L^{JH}	L^{JO}	L^{JW}	Q^{J}	X^{J}
U.S.A.	(AU)	A^{UI}	A^{UM}	A^{UP}	A^{US}	A^{UT}	A^{UC}	A^{UN}	A^{UK}	A^{UJ}	A^{UU}	F^{UI}	F^{UM}	F^{UP}	F^{US}	F^{UT}	F^{UC}	F^{UN}	F^{UK}	F^{UJ}	F^{UU}	L^{UH}	L^{UO}	L^{UW}	Q^{U}	X^{U}
Freight and Insurance	(BF)	BA^{I}	BA^{M}	BA^{P}	BA^{S}	BA^{T}	BA^{C}	BA^{N}	BA^{K}	BA^{J}	BA^{U}	BF^{I}	BF^{M}	BF^{P}	BF^{S}	BF^{T}	BF^{C}	BF^{N}	BF^{K}	BF^{J}	BF^{U}					
Import from H. Kong	(CH)	A^{HI}	A^{HM}	A^{HP}	A^{HS}	A^{HT}	A^{HC}	A^{HN}	A^{HK}	A^{HJ}	A^{HU}	F^{HI}	F^{HM}	F^{HP}	F^{HS}	F^{HT}	F^{HC}	F^{HN}	F^{HK}	F^{HJ}	F^{HU}					
Import from EU	(CO)	A^{OI}	A^{OM}	A^{OP}	A^{OS}	A^{OT}	A^{OC}	A^{ON}	A^{OK}	A^{OJ}	A^{OU}	F^{OI}	F^{OM}	F^{OP}	F^{OS}	F^{OT}	F^{OC}	F^{ON}	F^{OK}	F^{OJ}	F^{OU}					
Import from the R.O.W.	(CW)	A^{WI}	A^{WM}	A^{WP}	A^{WS}	A^{WT}	A^{WC}	A^{WN}	A^{WK}	A^{WJ}	A^{WU}	F^{WI}	F^{WM}	F^{WP}	F^{WS}	F^{WT}	F^{WC}	F^{WN}	F^{WK}	F^{WJ}	F^{WU}					
Duties & Import Taxes	(DT)	DA^{I}	DA^{M}	DA^{P}	DA^{S}	DA^{T}	DA^{C}	DA^{N}	DA^{K}	DA^{J}	DA^{U}	DF^{I}	DF^{M}	DF^{P}	DF^{S}	DF^{T}	DF^{C}	DF^{N}	DF^{K}	DF^{J}	DF^{U}					
Value Added	(VV)	V^{I}	V^{M}	V^{P}	V^{S}	V^{T}	V^{C}	V^{N}	V^{K}	V^{J}	V^{U}															
Total Inputs	(XX)	X^{I}	X^{M}	X^{P}	X^{S}	X^{T}	X^{C}	X^{N}	X^{K}	X^{J}	X^{U}															

Figure 5-1. Layout of the 2005 Asian international input-output table.

This study uses the 2005 AIIO table for evaluating the social inventory database that consists of 76 economic sectors and 10 countries. The social issues in this analysis include the total employment, paid workers, vulnerable employment, wages, and fatal and non-fatal occupational injuries. Definitions of the economic sectors for the AIIO table are shown in Table C-1, in the Appendix C. This study divided the economic sectors into three categories: primary sector (IO code 01–11), secondary sector (IO code 12–64), and tertiary sector (IO code 65–76). The primary sector is the sector of an economy making direct use of natural resources; this consists of agriculture, forestry, fishing and mining. The secondary sector is the economic sectors that manufactures finished products as well as construction. The tertiary sector, also known as the service industry, includes information technology, education, and financial services.

The AIIO tables consist of 10 countries in the Asia-Pacific region: Japan (J), the US (U) and eight Asian countries China (C), South Korea (K), Taiwan (N), Singapore (S), Thailand (T), Malaysia (M), Indonesia (I), and Philippines (P). Based on this data, the input–output coefficient matrix is then illustrated as Equation (5-1).

$$A = \left(\frac{X_{ij}^{\alpha\beta}}{X_j^{\beta}} \right) = \begin{bmatrix} A^{II} & A^{IM} & \cdots & A^{IJ} & A^{IU} \\ A^{MI} & A^{MM} & \cdots & A^{MJ} & A^{MU} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ A^{JI} & A^{JM} & \cdots & A^{JJ} & A^{JU} \\ A^{UI} & A^{UM} & \cdots & A^{UJ} & A^{UU} \end{bmatrix} \quad (5\text{-}1)$$

where α is a supplying country code of goods and services; β is a demanding country code of goods and services; i is industry i of country α ; j of country β , and $X_{ij}^{\alpha\beta}$ is an element of the intermediate matrix; X_j^{β} is an element of the gross output vector.

Let $F_{ik}^{\alpha\beta}$ be a category k final demand of the country/region β for the product i of country/region α. Like the same feature as in the intermediate matrices on the above, the final demand matrix in the AIIO tables is explained as per Equation (5-2).

$$F = \left(F_{ik}^{\alpha\beta} \right) = \begin{bmatrix} F^{II} & F^{IM} & \cdots & F^{IJ} & F^{IU} \\ F^{MI} & F^{MM} & \cdots & F^{MJ} & F^{MU} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ F^{JI} & F^{JM} & \cdots & F^{JJ} & F^{JU} \\ F^{UI} & F^{UM} & \cdots & F^{UJ} & F^{UU} \end{bmatrix} \quad (5\text{-}2)$$

It is then understood that the direct and indirect impacts of final consumption of country β on output, $X^{F^{\beta}}$, can be determined by Equation (5-3).

$$X^{F^{\beta}} = \left(I - A \right)^{-1} F^{\beta} \quad (5\text{-}3)$$

where $(I - A)^{-1}$ is the Leontief inverse matrix that represents the total effect of both direct and direct inputs to fulfill one unit of final consumption in monetary value; I is the identity matrix.

Let L as the total social inputs required to satisfy the final consumption, or the social footprint. The social extensions are total employment, paid workers, vulnerable employment, wages, fatal accidents and non-fatal occupational injuries, for economic sectors as calculated in social footprints. We can extend the IO relationship derived Equation (5-3) as:

$$L^{\beta} = l^{\beta} X^{F^{\beta}} = l^{\beta} \left(I - A \right)^{-1} F^{\beta} \quad (5\text{-}4)$$

where L^{β} is the direct and indirect social vector or social footprint vector of country β, l^{β} is the diagonal matrix of social coefficient of country β.

5.2.3 Assumptions and limitations

The applying IOA in this study involves some assumptions summarized in the following:

- Constant technological coefficients: the amount of input necessary to produce one unit of output is assumed to be constant in the short term, regardless to price effects, changes in technology or economies of scale.
- Linear production functions: the IOA assumes that if the output level of industry changes, the input requirements will change proportionally.
- It is assumed that each economic sector produces and sells one and only one homogeneous good.
- There are no resource constraints. Supply is assumed infinite and perfectly elastic.
- Local resources are efficiently employed. There is no underemployment of resources.
- IO tables describe an economy in a specific period; they do not highlight the trend of the economic interrelationship in a long time.
- This study was considered effect within 10 Asian countries and import from the rest of the world (RoW). This implies that all reflections come from final demand do not necessarily influence Asian production; some effects may influence imports from the RoW. It is, therefore, necessary to provide for the method of calculating the coefficient matrix inversion, which accounts for imported inputs. Imports from the RoW implicitly assumes that the same production characteristics and technologies as comparable products made in the Asian countries. In addition, the analysis in this study is based on the assumption that the RoW would have the same labor intensities for 'equivalent' economic sector of the country being studied. This is because the labor consumed by the RoW is not known, and calculating it would require the high resolution multi-region IO (MRIO) tables and labor consumption data.
- In the cases of missing data and aggregated data, the allocation of social aspects into AIIO sector was carried out based on the employment share of each sector, which adopted from Simas et al. (2014). We assumed that, within a major sector, the incidence rate per employees in each sub-sector was similar. Major sector is considered the aggregated sector classification from the original data. This is a limitation of this study,

and provides a basis for further research as more data become available. In addition, in some countries, we used the fatality rate and incidence rate per employees of each sector based on the national statistical data to estimate the number of fatal and non-fatal cases of each economic sector.

5.2.4 Data sources and data processing

This study established the social intensity database using the 2005 AIIO table. The social intensity developed in this study consisted of total employment, paid workers, vulnerable employment, wages, and fatal and non-fatal occupational injuries. The definition of the social indicators in this study is presented in Section 5.2.1. The model represents a picture of the Asian international economy and labor conditions in 2005. Before applying IOA, the collected data must be harmonized with the compatible IO table form. This can be done by following tables are consistent with the classification of IO table and specification of each industrial sector. The data sources and compatible with IO table are presented in Table 5-2.

Table 5-2. Data sources and compatibility with AIIO table.

Item	Source	Compatibility
Employment (10 countries)	IDE-JETRO (2013)	76 sectors
Paid worker (10 countries)	IDE-JETRO (2013)	76 sectors
Vulnerable employment (10 countries)	IDE-JETRO (2013)	76 sectors
Wage (10 countries)	IDE-JETRO (2013)	76 sectors
Occupational injuries and fatality of USA	U.S. Bureau of Labor Statistics (2007)	65 sectors
Occupational injuries and fatality of Thailand	Thailand Social Security Office (2006)	55 sectors
Occupational injuries and fatality of Korea	Korea Ministry of Employment and Labor (2014)	47 sectors
Occupational injuries and fatality of Japan	ILO (2014)	16 sectors
Occupational injuries and fatality of Taiwan	ILO (2014)	16 sectors
Occupational injuries and fatality of Singapore	Singapore Ministry of Manpower (2006)	18 sectors
Occupational injuries and fatality of Malaysia	Abas et al. (2011); Abas et al. (2013)	17 sectors
Occupational injuries and fatality of China	ILO Office for China and Mongolia (2012); National Bureau of Statistics of China (2006)	14 sectors
Occupational injuries and fatality of the Philippines	Philippines Bureau of Labor and Employment Statistics (2003; 2007)	45 sectors
Occupational injuries and fatality of Indonesia	Irfani (2015); Latief et al. (2011)	6 sectors

The data mapping steps of the social inventory data into the socially extended input-output model are presented in Figure 5-2.

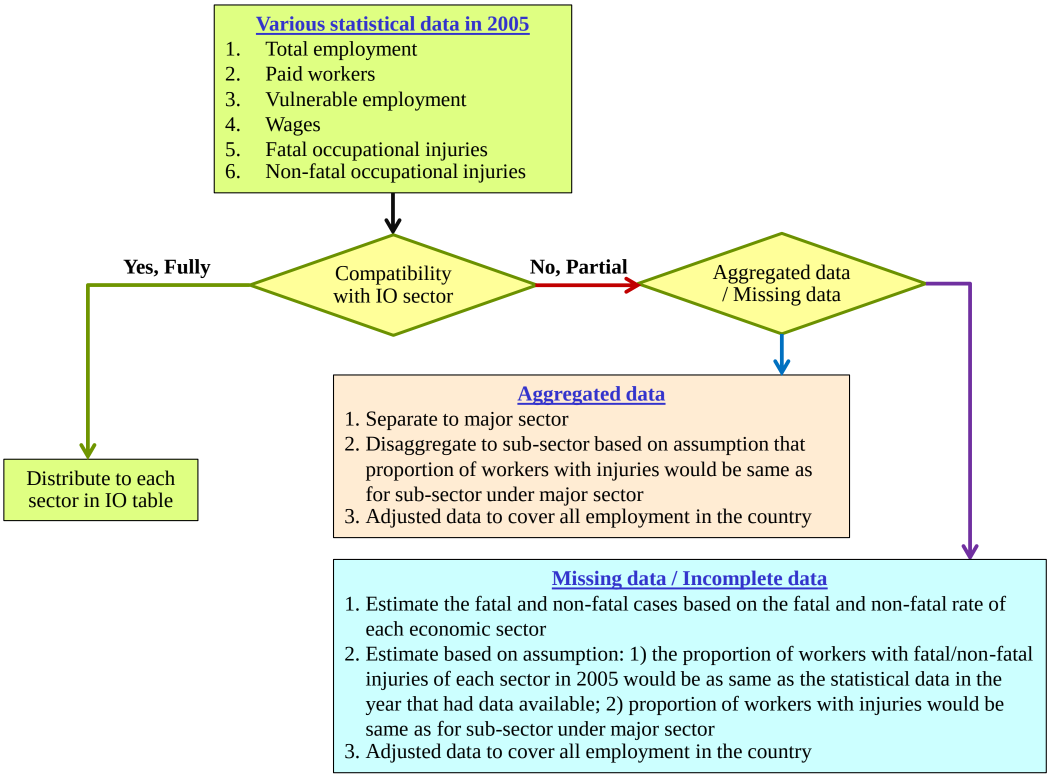

Figure 5-2. Data mapping steps of the social data into the AIIO table.

The statistical data for the total employment, paid workers, and vulnerable employment of 10 Asian countries and 76 economic sectors in 2005 was obtained from IDE-JETRO [27]. The IDE-JETRO [27] provide the 76 economic sectors data on all employment statuses for each country in the study. We assumed the vulnerable employment pertains to most workers who come under the employment status groups of self-employed and unpaid family workers. In a similar way, the wages intensity of each economic sector of 10 Asian countries in 2005 was calculated using the data from the AIIO table [28].

The statistical data for the non-fatal and fatal occupational injuries of each country were obtained from both national and International Labour Organization (ILO) databases. These databases included only formal workers or permanent workers as defined under the social security law of each country and was based on data in 2005 in accordance with the 2005 AIIO table. The labor that worked in the informal market was excluded in the occupational injuries statistics.

Occupational injuries data from ILO consist of 10–16 economic sectors, whereas national statistical data of each country cover 30–65 industry sectors, which provides better information on economic sector than the data from ILO. The fatal and non-fatal injuries inputs were distributed across a wide variety of economic sectors and allocated to each industry in the AIIO according to the proportion of workers with injuries per economic sector. The separation was calculated based on the assumption that, for the major economic sector, the proportion of workers with injuries would be same as for specific economic sectors under major sector. The fatal and non-fatal occupational accident information of both national and ILO data sources covers only wage employees.

For the US, the number of fatal and non-fatal accidents was taken from the webpage of the Bureau of Labor Statistics, U.S. Department of Labor [29,30]. Currently, the US statistical data cover also self-employed persons and farmers. It is seen that approximately 97.75% of all fatal accidents are covered in the US statistics. The total fatal accidents for the US were corrected using this ratio (100%/97.75% = 1.02) whereas non-fatal accidents were corrected using this ratio (100%/83.18% = 1.20). The statistical data of Japan and Taiwan were gathered from the ILO [31]. It is found that around 82.91% of all fatal accidents in Japan is covered in the ILO databases. The total fatal and non-fatal accidents for Japan were corrected using this ratio (100%/82.91% = 1.21). Meanwhile, for Taiwan, the total fatal and non-fatal accidents were adjusted using the ratio of (100%/73.32% = 1.36). These data for Thailand were obtained from Thailand’s Social Security Office (SSO) [32]. It is found that only 23.23% of all fatal accidents in Thailand are covered in the SSO databases. The total fatal and non-fatal accidents for Thailand were adjusted using the ratio of (100%/23.23% = 4.30). South Korean data were gathered from ILO [31] and Korea Ministry of Employment and Labor [33]. The total fatal and non-fatal accidents for Korea were adjusted using this ratio (100%/70.34% = 1.42). For Singapore, the data were gathered from the workplace injuries statistics database of the Occupational Safety and Health Division, Singapore Ministry of Manpower [34]. The total fatal and non-fatal accidents for Singapore were adjusted using the ratio of (100%/95.22% = 1.05). The fatal occupational injuries data of Malaysia were obtained from Abas et al. [35], whereas non-fatal occupational injuries were obtained from Abas et al. [36]. It is showed that around 75.49% of all fatal and non-fatal accidents in Malaysia are covered in these previous studies. The total fatal and non-fatal accidents for Malaysia were corrected using this ratio (100%/75.49%=1.55).

For the Philippines, we estimated the fatal and non-fatal occupational injuries using the average incidence rate and fatality rate from the Philippines Bureau of Labor and Employment

Statistics in 2003 and 2007 [37]. We calculated based on the assumption that the proportion of workers involved in an accident in each economic sector was steady on the whole. In addition, we found that only 5.70% of all fatal and non-fatal accidents in Philippines is covered in these databases. The total fatal and non-fatal accidents for Philippines were adjusted using the ratio of (100%/5.70% = 17.54).

In China, we used the fatality rate per economic sector from the national profile report on occupational safety and health in 2005 to estimate the fatal workplace accident cases [38] and worked under the same assumption of the Philippines. For the non-fatal occupational injuries, we estimated the total non-fatal cases from the statistical data on non-fatal work injuries of the National Bureau of Statistics of China [39] and allocated them to each economic sector based on the fatal accident cases of China [38]. We found that only 14.31% of all fatal and non-fatal accidents in China are covered in these data sources. The total fatal and non-fatal accidents for China were corrected using the ratio of (100%/14.31% = 6.99).

For Indonesia, the total number of fatal and non-fatal workplace injuries in 2005 was obtained from Irfani [40]. We distributed the data on fatal and non-fatal cases across each economic sector based on the assumption that the proportion of workers with fatal and non-fatal injuries of each economic sector in 2005 would be same as the statistical data on injuries in each economic activity in 2009 in Indonesia [41]. We allocated the fatal and non-fatal injuries overall into each sector under the same assumption used for the Philippines. In addition, we found that only 13.92% of all fatal and non-fatal accidents in Indonesia are covered in these data sources. The total fatal and non-fatal accidents for Indonesia were corrected using the ratio of (100%/13.92% = 7.18).

5.2.5 Sensitivity analysis in this study

Due to the fatal and non-fatal statistical data of each country are usually not covered all economic sectors, the quality of these data is usually based on estimates, and therefore carry a great deal of uncertainty. Sensitivity is the influence that one parameter (the independent variable) has on the value of another (the dependent variable), both of which may be either continuous or discrete. In this study, sensitivity analysis was considered as following:

- Assumption change on the fatal occupational injury intensity: (1) calculation the missing data in the manufacturing sector of Japan using the fatal rate in sub-sector of USA; (2) estimation the missing data in the manufacturing sector of Indonesia by using the fatal rate of manufacturing sector in the Philippines (average of 2003 and 2007) and in the year 1997 of

Indonesia [42]; (3) change in the fatal rate of manufacturing sector of China (+10% and +20% fatal rate).

- Change in the type of database and country difference on the employment intensity and employment footprint: calculate the employment intensity and employment footprint by using the high-resolution multi-region IO (MRIO) tables such as ADB MRIO.

5.3 Results

5.3.1 Total employment

5.3.1.1 Total employment intensity

Total employment intensity, measured by labor inputs in terms of person-year per 1000 US$ output for 10 countries with 76 industrial sectors is shown in Figure 5-3. The result shows that this is one magnitude higher in the developing countries than in the developed countries (Japan and USA). Particularly, labor input was of the same magnitude in agricultural sectors. For example, in Thailand, the employment intensity is approximately 5–34 times greater than that in Japan and is about 13–60 times greater than that in the USA. In China, the employment intensity of agriculture sectors is 6–58 times higher than that in Japan and is approximately 50–65 times higher than that in the USA. Generally, the employment intensity in agricultural crops (IO code 1–4), livestock (IO code 5), forestry (IO code 6), and fishery (IO code 7) sectors are higher than other sectors, especially in developing countries. Due to agriculture in developing countries being so labor intensive, the agricultural sector has the highest employment intensity. The next was the tertiary sector and secondary sector, respectively. The employment intensity deduced in this study demonstrated similar trends to the results obtained by Papong et al. [21]. Top-ranking employment intensity is common in developing countries including China, Indonesia, Philippines, Thailand, and Malaysia. Whereas, bottom-ranking employment intensity is more common in developed countries and higher income countries (USA, Japan, Korea, Taiwan, and Singapore, respectively).

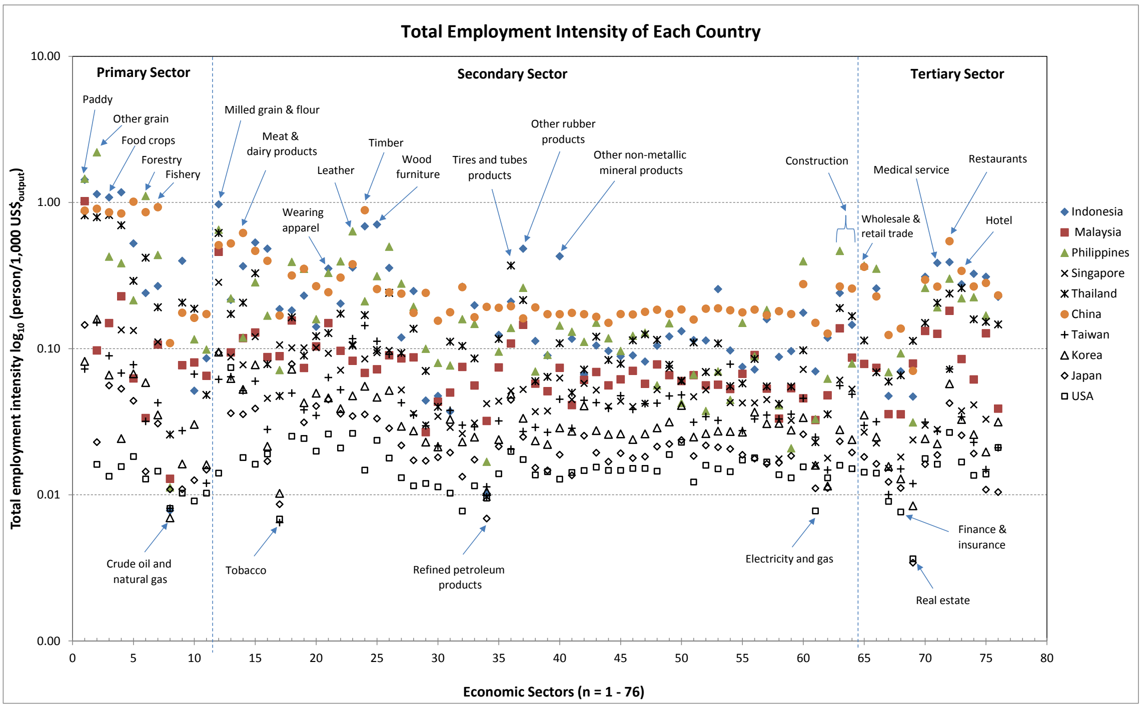

Figure 5-3. Comparison the total employment intensity from cradle to gate of 10 countries by economic sector.

When considering the primary sector (IO code 1–11), the employment intensity in terms of (person/1000 US$ output) of the paddy sector is highest in Indonesia (1.42), Philippines (1.39), and Malaysia (1.00). The other grain sectors are highest in Philippines (2.13), Indonesia (1.14), and China (0.90). The food crop sector is highest in Indonesia (1.08), China (0.85), and Thailand (0.80). Meanwhile, the crude oil and natural gas sector is lowest in all countries. When considering the employment intensity of the secondary sector (IO code 12–64), the results showed that the milled grain and flour sector is superb in almost all countries except China, Taiwan, and the USA. The timber sector is highest in China (0.88) and Indonesia (0.67), whereas in the USA the lowest can be found in the tobacco sector (0.007). The top-ranking employment intensity of Indonesia is in the milled grain and flour (0.98), wooden furniture (0.70), timber (0.67), other food products (0.53), and other rubber products sectors (0.49), respectively. In Malaysia, the top five employment intensities can be found in milled grain and flour (0.47), spinning (0.15), clothing apparel (0.15), other rubber products (0.15), and the building construction sectors (0.13), respectively. Top-ranking intensities in the Philippines are milled grain and flour (0.63), leather and leather products (0.61), other wooden products (0.48), and the building construction sector (0.43), respectively. The top five employment intensities of Thailand are milled grain and flour (0.59), tires and tubes (0.37), other food products (0.33), other wooden products (0.24), and other rubber products (0.21), respectively. Top-ranking intensities in China are in timber (0.88), meat and dairy products (0.62), fish products (0.53), milled grain and flour (0.51), and other food products (0.47), respectively. It was shown that the majority of these sectors are part of the supply chain. The tobacco sector has the lowest employment intensity in the USA, Japan, South Korea, and Taiwan. The bottom-ranking employment intensities in the USA are found in tobacco (0.007), electricity and gas (0.008), drugs and medicine (0.008) and the refined petroleum sectors (0.010), respectively. In Japan, the bottom-ranking intensities are in tobacco (0.009), water supply (0.012), and electricity and gas sectors (0.013). In South Korea and Taiwan, the bottom-ranking intensity sectors are in tobacco, water supply, and refined petroleum. While, the bottom-ranking sectors of Singapore are the other transport equipment, water supply, and electricity and gas sectors. For the tertiary sector (IO code 65–76), the results show that the restaurants sector has the highest employment intensity in almost all countries except the Philippines (highest in the wholesale and retail trade sector) and Thailand (highest in the hotel sector). While, the real estate sector has the lowest intensity in Japan (0.003), USA (0.004), South Korea (0.009), Taiwan (0.012), and Singapore (0.026). The finance and insurance sector is the lowest in USA (0.008), Japan (0.011), and Korea (0.013).

5.3.1.2 Employment footprint per capita

Figure 5-4 offers a breakdown of the share of the total employment footprint from final demand per capita for each country. These are presented for imported products and goods produced domestically. The share of employment footprint is usually highest for domestic production in China, Thailand, Malaysia, Indonesia, and the Philippines, while China is always highest for imports into the USA, Japan, Singapore, Korea, and Taiwan. The developed countries (USA and Japan) dominate the top-ranking master country positions, whereas the richest Asian countries (South Korea, Taiwan, and Singapore) dominate the medium-ranking master countries. To satisfy consumption, each American requires seven-tenths of one worker to sustain their lifestyle. This consists of domestic workers (70%) and foreign workers (30%). In total, 77% of the imports' workforce is from China. Each Japanese citizen needs eight-tenths of one worker to preserve their standard of living, which comes from the domestic (63%) and foreign workforce (37%). The imported workforce from China was estimated at 78% of total imports. Each person in Singapore needs six-tenths of one worker to maintain their lifestyle, which comes from the domestic workforce (37%) and foreign workforce (63%). The imported workforce from China and Indonesia was estimated at 39% and 36% of total imports, respectively. Meanwhile, each person in South Korea, Taiwan, and China require half of one full-time worker to sustain their lifestyles. Sixty percent of workers in South Korea and Taiwan can support their final consumption, whereas 99% of the workers in China can support their consumption. Each Thai person needs only four tenths of one full-time worker to sustain their lifestyle, consisting of domestic workers (89%) and foreign workers (11%). While, each one in Indonesia, Malaysia, and the Philippines needs only one-third of one full-time worker to support their final consumption. Based on these results, it shows that the Chinese worker is largely engaged in exports, but their exports do not generate jobs in other countries. However, the domestic employment footprint of each country is included imported from the rest of the world (RoW) based on assumptions that imports from the RoW implicitly assumes that the same production characteristics and technologies as comparable products made in the interested country (Section 5.2.3).

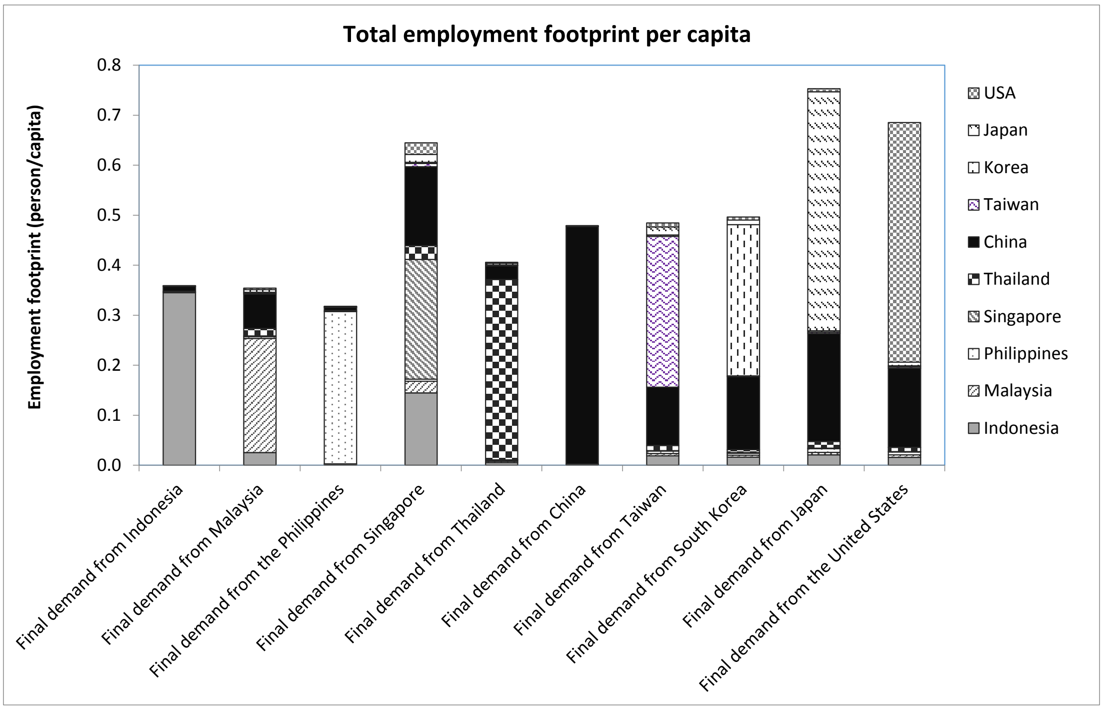

Figure 5-4. Comparison the total employment footprint per capita for each country.

5.3.2 Paid worker

5.3.2.1 Paid worker intensity

Paid worker intensity is measured through employee input in terms of person-year per 1000 US$ output of 10 countries within 76 industrial sectors is presented in Figure 5-5. For middle-income countries (Thailand, Indonesia, and the Philippines, except China and Malaysia), the paid worker intensity in the agricultural crops sectors is higher than for other sectors. Agriculture cultivation in a developing country is labor intensive and of low economic value, whereas, in high-income countries (USA, Japan, Korea, Singapore, and Taiwan), the tertiary sector has a higher paid worker intensity than in the secondary and primary sectors, respectively. Top-ranking paid worker intensity in developing countries include the Philippines, Indonesia, China, Thailand, and Malaysia, respectively. Whereas, bottom-ranking paid worker intensity occurs in the high-income countries (USA, Japan, Korea, Taiwan, and Singapore, respectively).

When considering the primary sector (IO code 1–11), the paid employment intensity of the forestry (0.37), paddy (0.35), and other grain (0.30) sector is highest in the Philippines, whereas in Indonesia the highest is in the paddy (0.25), non-food crops (0.21), and other grain (0.20) sectors, respectively. For the livestock sector (IO code 5), paid worker intensity is highest in China (0.10) and Thailand (0.07), while the paid worker intensity of the iron mining sectors (IO code 9) is highest in Indonesia (0.185), and Thailand (0.176). The lowest paid employment intensity can be found in the crude oil and natural gas sectors (IO code 8) in all countries.

When considering the paid employment intensity of the secondary sector (IO code 12–64), the results showed that the timber sector (0.49) is the highest in Indonesia, whereas in the Philippines, it can be found in the leather products sector (0.40). The milled grain and flour sector is the highest in Indonesia (0.19), the Philippines (0.15), and Thailand (0.14), whereas the meat and dairy products sector it is the highest in China (0.11), Indonesia (0.10), and Thailand (0.07). Top-ranking paid employment intensity of Indonesia can be found in the timber (0.49), wooden furniture (0.41), wearing apparel (0.24), other non-metallic mineral products (0.23), and leather products (0.20) sectors, respectively. In Malaysia, the top three paid worker intensity sectors are the spinning (IO code 18), wearing apparel (IO code 21), and the building construction (IO code 63) sectors, respectively. Top-ranking intensities in the Philippines can be found in the leather and leather products (0.40), building construction (0.38), and other rubber products (0.17) sectors, respectively. The top three paid employment intensities in Thailand can be found in the building construction (0.14), milled grain and flour (0.14), and other rubber products (0.13) sectors, respectively. The top-ranking paid worker intensity in China is in the meat products and dairy products (0.11), wearing apparel (0.10), wooden furniture (0.10), and leather products (0.09) sectors, respectively. The majority of these sectors employ paid workers in the supply chain. While, the paid worker intensity for the tobacco sector is the lowest in USA, Japan, South Korea, and Taiwan. The bottom-ranked paid employment intensity of USA is the tobacco (0.004), electricity and gas (0.007), drugs and medicine (0.007), and refined petroleum (0.008) sectors, respectively. In Japan, the bottom-ranking intensities are found in the tobacco (0.004), refined petroleum (0.009), water supply (0.009), and electricity and gas (0.009) sectors. The bottom-ranked paid worker intensities in

South Korea are in the tobacco (0.004), water supply (0.009), refined petroleum (0.011), and electricity and gas (0.012) sectors. The bottom-ranking intensities of Taiwan are in the tobacco (0.004), refined petroleum (0.012), and water supply (0.013) sectors, whereas for Singapore it is the electricity and gas (0.011) and water supply (0.015) sectors, respectively.

For the tertiary sector (IO code 65–76), the results showed that the education and research sector has the highest paid employment intensity in Indonesia (0.26), the Philippines (0.24), Thailand (0.13) and China (0.13) whereas the transport sector has the highest intensity in the Philippines (0.18), China (0.11) and Indonesia (0.09). The paid employment intensity of China is the highest in the wholesale and retail trade sector (0.17). While, the real estate sector has the lowest intensity in Japan (0.0026), USA (0.0030), and South Korea (0.0065). The finance and insurance sector is the lowest in USA (0.007), Japan (0.010), Korea (0.011), Taiwan (0.014), and Singapore (0.016).

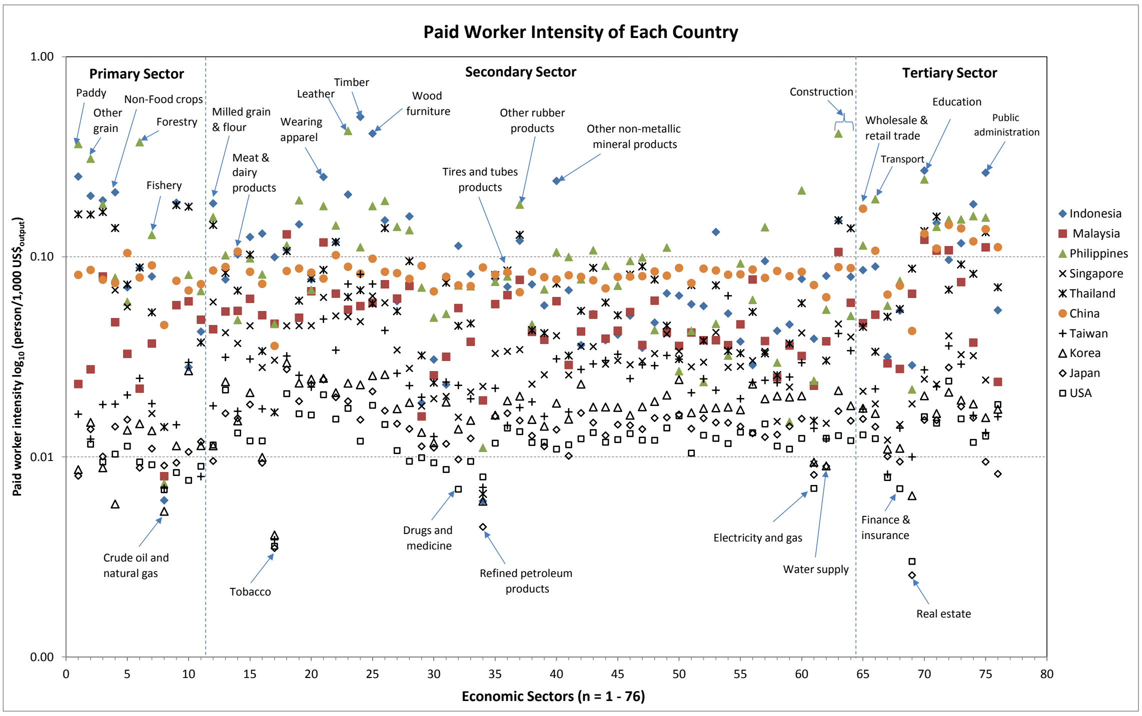

Figure 5-5. Comparison the paid worker intensity from cradle to gate of 10 countries by economic sector.

5.3.2.2 Paid worker footprint per capita

Figure 5-6 provides a breakdown of the share of the paid employment footprint from final demand per capita for each country. This demonstrates the extent of paid workers involved in the production of imported goods and products manufactured domestically in each country. The share of paid workers in the footprint is usually dominated by domestic production in all countries. However, China always has the highest share of imports into USA, Japan, Singapore, South Korea, and Taiwan.

To satisfy its level of consumption, each person in the USA and Japan need a half of one full-time worker to maintain their living, which comprises of domestic paid workers (80%) and overseas workers (20%). However, 70% of the paid workers of imported products are from China. Each person in Singapore needs four-tenths of one full-time worker to support their lifestyle, which comes from domestic paid workers (56%) and overseas paid workers (44%). The imports from China and Indonesia were estimated at 30% and 31% of total imports, respectively. While, each person in South Korea and Taiwan requires three-tenths of one full-time worker to sustain their lifestyle. Seventy percent of paid workers in South Korea and Taiwan can support their final consumption. Each person in Thailand and Malaysia needs only two-tenths of one full-time worker to maintain their lifestyle, whereby 89% and 76% of this share are domestic paid workers for Thailand and Malaysia, respectively. Whereas, each person in China, Indonesia, and the Philippines requires only one-tenth of one full-time worker to support their final consumption. However, the domestic paid workers of each country are included imported from the RoW based on assumptions in the section 5.2.3.

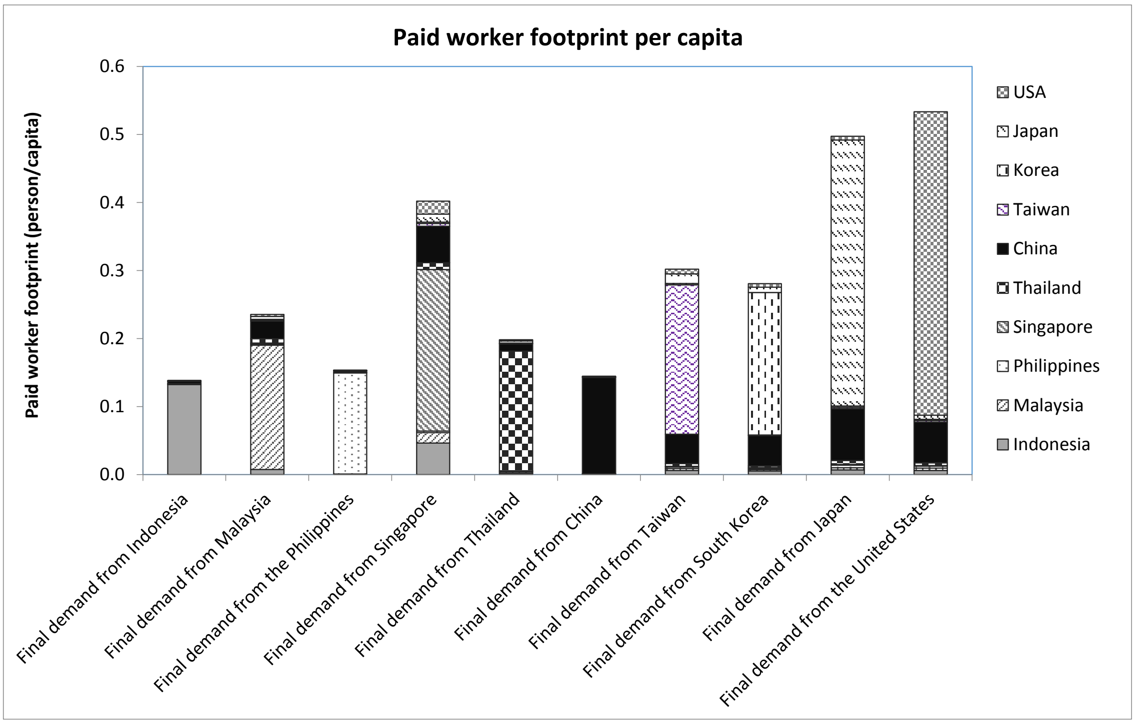

Figure 5-6. Comparison the paid worker footprint per capita for each country.

5.3.3 Vulnerable employment

5.3.3.1 Vulnerable employment intensity

Vulnerable employment is calculated as the sum of own-account workers and unpaid family workers. Many vulnerable workers suffer because they do not legally count as employees and are therefore without social security. Vulnerable employment intensity is expressed in terms of person-year per 1000 US$ output of 10 countries with 76 industrial sectors, and is shown in Figure 5-7. Vulnerable employment intensity is measured based on economic production and consumption. This is particularly high for China, Indonesia, the Philippines, and Thailand, due to their high levels of informal labor, especially in the agriculture sector. Developed countries (USA and Japan) have very low levels of vulnerable employment intensity, whereas, medium level vulnerable employment intensity is found in Malaysia, Singapore, Taiwan, and South Korea, respectively.

When considering the primary sector (IO code 1–11), the vulnerable employment intensity of developing countries is the highest in the paddy sector of Indonesia (1.17), the Philippines (1.04) and Malaysia (0.97), whereas, the non-food crops sector has the highest intensity in Indonesia (0.96), China (0.76), and Thailand (0.55). While, the vulnerable worker intensity of the forestry sector is the highest in China (0.77), the Philippines (0.73), and Thailand (0.33). The lowest vulnerable employment intensity can be found in the crude oil and natural gas sector in almost all countries. However, the vulnerable worker intensity of developed countries (USA and Japan) and the richest Asian countries (Singapore, Taiwan, and South Korea) is lower than that of developing countries.

When considering the vulnerable employment intensity of the secondary sector (IO code 12–64), the results showed that the milled grain and flour sector has the highest intensity of vulnerable workers in most countries except China (highest in the timber sector), Taiwan (highest in the timber sector), and USA (fish products sector, IO code 13). The top three vulnerable employment intensities of Indonesia can be found in the milled grain and flour (0.79), other rubber products (0.37), and wooden furniture (0.29) sectors, respectively. For Malaysia, the top-ranked vulnerable worker intensities are in the milled grain and flour (0.43), other rubber products (0.07), and meat products and dairy products (0.07) sectors, respectively. Top-ranking vulnerable worker intensities of the Philippines can be found in the milled grain and flour (IO code 12), other wooden products (IO code 26), spinning (IO code 18), other made-up textile products (IO code 22), and leather products sectors (IO code 23), respectively. In Thailand, the top five vulnerable employment intensities are in the milled grain and flour (0.45), tires and tubes (0.23), other food products (0.23), meat and dairy products (0.14), and timber sectors (0.11), respectively. Top-ranking vulnerable worker intensities in China are found in the timber (0.80), meat and dairy products (0.51), fish products (0.43), and milled grain and flour (0.43) sectors, respectively. It was shown that the majority of these sectors are made up of vulnerable workers in their supply chains. However, the vulnerable worker intensity of the USA is the lowest, followed by Japan and South Korea.

For the tertiary sector (IO code 65–76), the results showed that the restaurant sector has the highest vulnerable employment intensity in almost all countries except for the Philippines (highest in the wholesale and retail trade sector). While, the real estate sector had the lowest vulnerable worker intensity in USA, Japan, South Korea, and Taiwan.

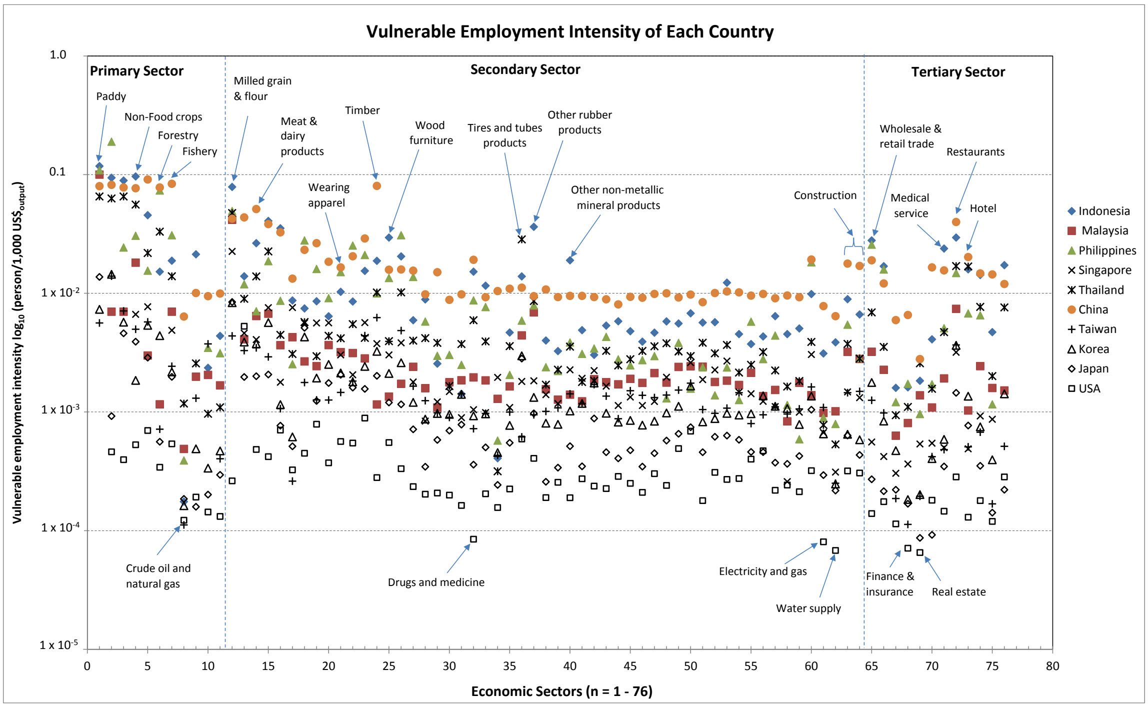

Figure 5-7. Comparison the vulnerable employment intensity from cradle to gate of 10 countries by economic sector.

5.3.3.2 Vulnerable employment footprint per capita

Figure 5-8 shows the results of the vulnerable employment footprint per capita of 10 countries. The results show that the USA, Japan, Korea, Taiwan, Singapore, and Malaysia have lower vulnerable employment footprints in domestically-traded goods than that of imports to those countries. While, Indonesia, the Philippines, China, and Thailand present the highest vulnerable employment footprint in domestically-traded goods.

The vulnerable employment footprints are associated with intra-country trade and, as a result, the majority of vulnerable employment footprints is associated with exchanges of goods and services from the developing countries to developed countries; imports from China to USA and Japan correspond to more than half of all vulnerable employment in inter-country trade. These trades are also responsible for over 63% and 55% of vulnerable employment, respectively. While, imports from Thailand, Indonesia, and the Philippines to these developed countries, however, account for only 1%–6% of total vulnerable employment in inter-country trade. Imports from China to Korea, Singapore, Taiwan, and Malaysia correspond to 45%, 44%, 36%, and 33% of all vulnerable employment embodied in inter-country trade, respectively. However, the domestic vulnerable employment embodied of each country are included imported from the RoW based on assumptions in the section 5.2.3.

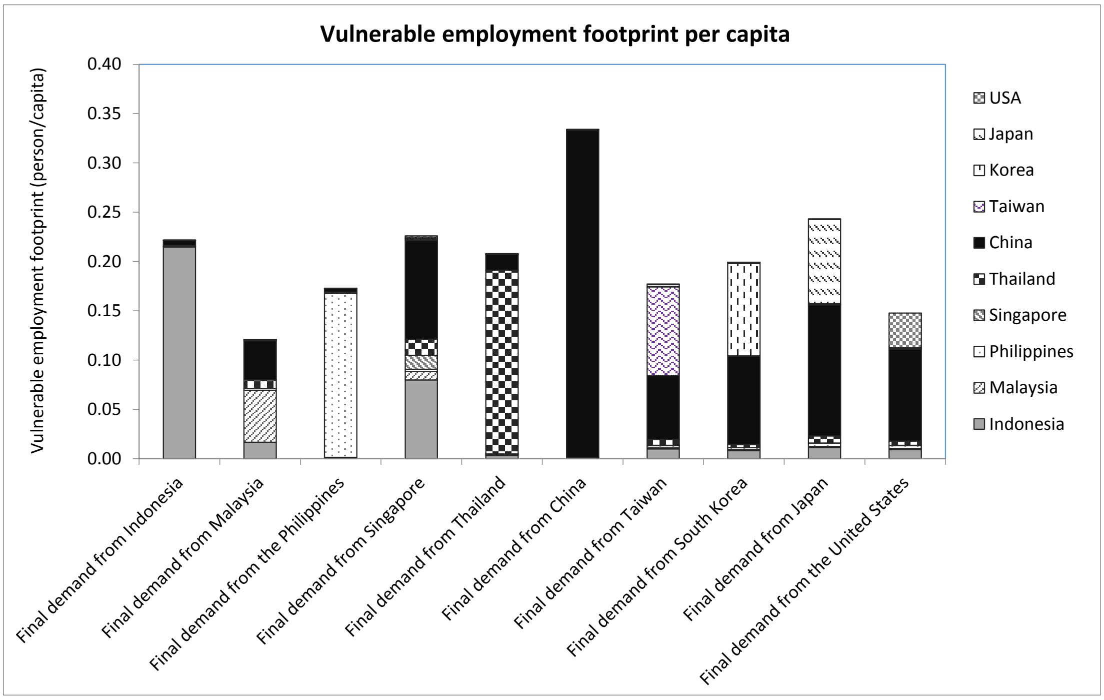

Figure 5-8. Comparison the vulnerable employment footprint per capita for each country.

5.3.4 Wages

5.3.4.1 Wages intensity

The IO table provides information on the average compensation paid to employees. The average wages of employees are different in each economic sector. Wages are a part of the production costs of each industrial sector. Thus, if a component of the production of any sector is used as an input for the production of other sectors, its increases wages affecting the production costs in other sectors as well.

The wages intensity measured in terms of one US$ wage per one US$ output of 10 countries with 76 economic sectors is given in Figure 5-9. The developed countries (USA and Japan) have a greater wage intensity than that of emerging and developing countries (Indonesia, the

Philippines, Thailand, China, and Malaysia) in almost all economic sectors. The higher wages intensity in the developed countries was due to those countries with higher wages rates. While, the richest Asian countries (South Korea, Taiwan, and Singapore) have higher wages intensities than developing countries but lower wage intensities than the developed countries. When comparing each economic sector, the results show that the education and research sector in all countries has the greatest wages intensity, followed by public administration and the medical and health service sectors, respectively.

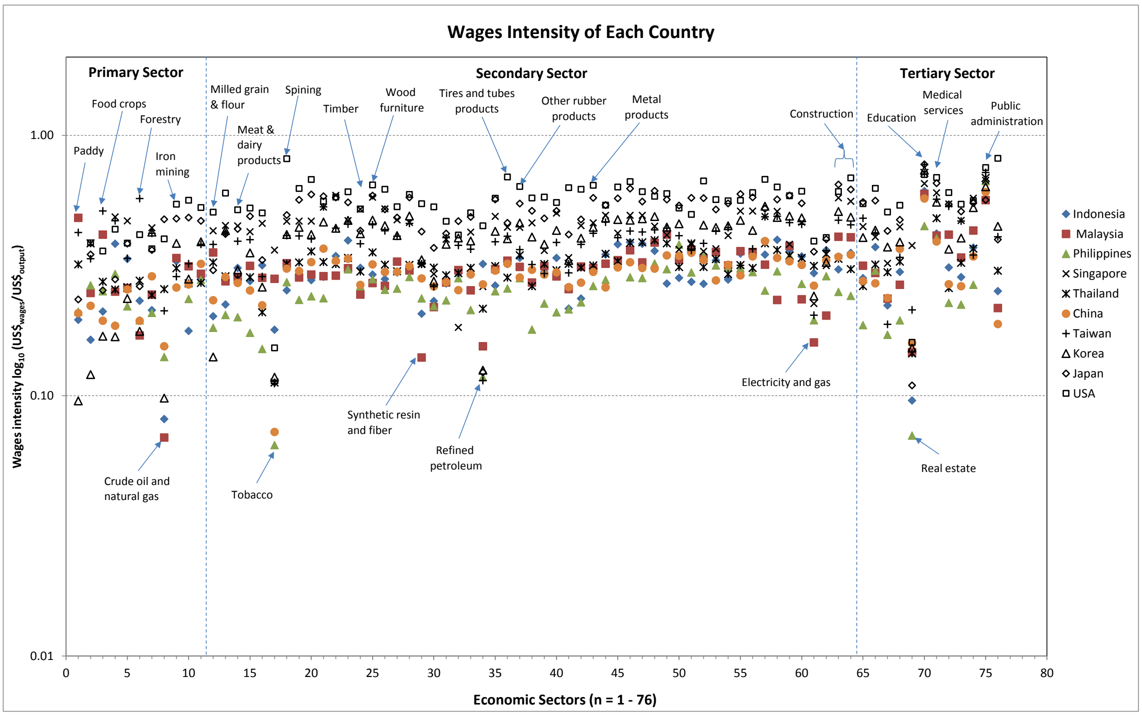

Figure 5-9. Comparison the wages intensity from cradle to gate of 10 countries by economic sector.

5.3.4.2 Wages footprint per capita

Figure 5-10 presents the results of the wages footprint per capita based on the final consumption of 10 Asian countries. The result showed that the USA has the highest wage footprint per capita, followed by Japan, Singapore, South Korea, and Taiwan. On the other hand, the Philippines has the lowest wage footprint per capita, followed by Indonesia, China, Thailand, and Malaysia. If we consider the case of Thailand, the wages footprint is approximately 1003 US Dollar per person, whereas USA's and Japan's generated wages footprints are estimated at about 23.6 and 17.1 times that of Thai people, respectively.

The domestic and overseas workers can be seen to support domestic consumption and standards of living. Lower paid workers produce goods and services throughout supply chains for more wealthy countries. China is a major exporter of labor to the USA. Based on a wage rate in 2005 of China of about US $2200/person/year [42,43], it takes approximately 1 million full-time equivalent (FTE) workers to generate US $2200 million of income. When comparing Japan as an exporter of labor to the USA, the same number of employees generated an income of US $35000 million (a wage rate of Japan about US $35,000/person/year) [44,45]. Thus, Japanese employees generated an income estimated at 16 times of Chinese employees. However, the domestic wage embodied of each country is included the effect of imported from the RoW based on assumptions in the section 5.2.3.

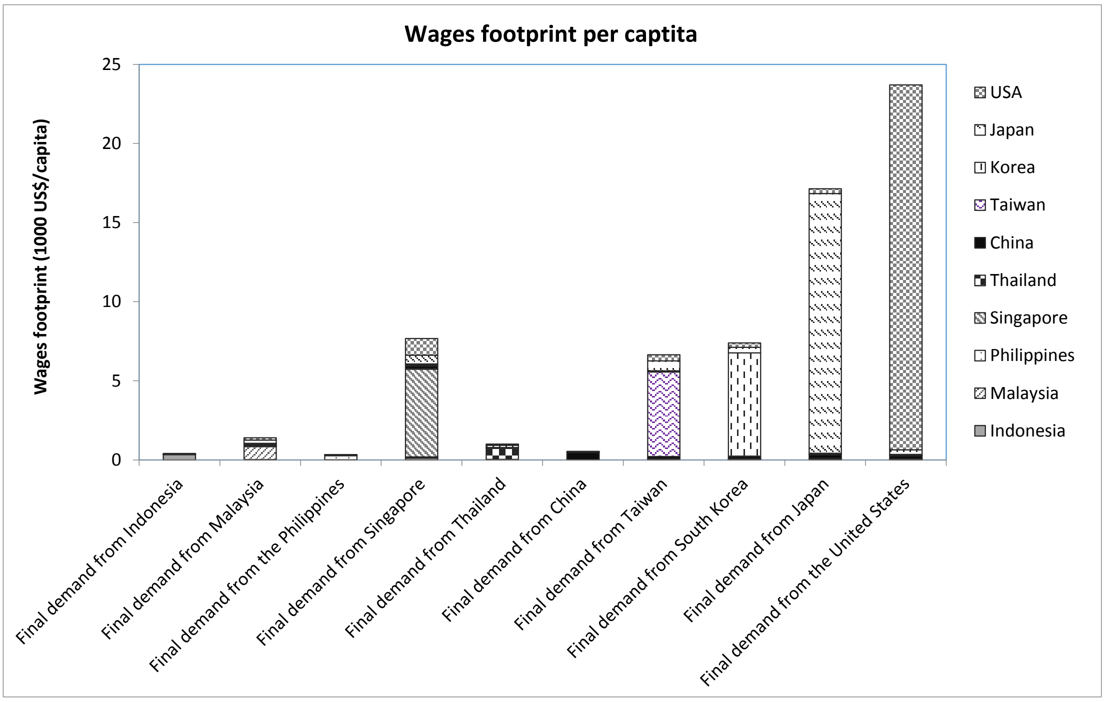

Figure 5-10. Comparison the wages footprint per capita for each country.

5.3.5 Non-fatal occupational injury

5.3.5.1 Non-fatal occupational injury intensity

Figure 5-11 presents the non-fatal occupational injury intensity of 10 countries with 76 industrial sectors based on the AIIO table of 2005. When considering the primary sector, the results show that the non-fatal occupational injury intensity of the forestry and iron mining sectors in Indonesia and the non-metallic ore and quarrying, other metallic mining, and iron mining sectors in China are the highest when comparing them with other sectors. With the coal mining sector in China having the highest risk rating in the world, the non-metallic ore and quarrying sector has the highest non-fatal intensity. In addition, the forestry sector in Indonesia also has a highest risk rating. The top five non-fatal occupational injury intensities can be found in China, Philippines, Indonesia, Thailand, and Malaysia, respectively. On the other hand, the bottom-ranked intensities are USA, Japan, South Korea, Taiwan, and Singapore.

Generally, agriculture in the developing countries has a high rate of employment and non-fatal injuries but low income intensity. In addition, the agriculture in developing countries is dominated by small-holder farming [46]. On the other hand, in developed countries, agriculture is usually performed on an industrial scale. In the developing countries, the mining sector similarly features high employment and non-fatal injury intensities, but mining in developed countries has a higher rate of injuries and low levels of employment [46]. Also, the non-fatal injuries intensity of the secondary sector and tertiary sector in developing countries is higher than that of developed countries. The non-fatal intensity established in our study was shown to have similar trends to the results obtained by Simas et al. [19].

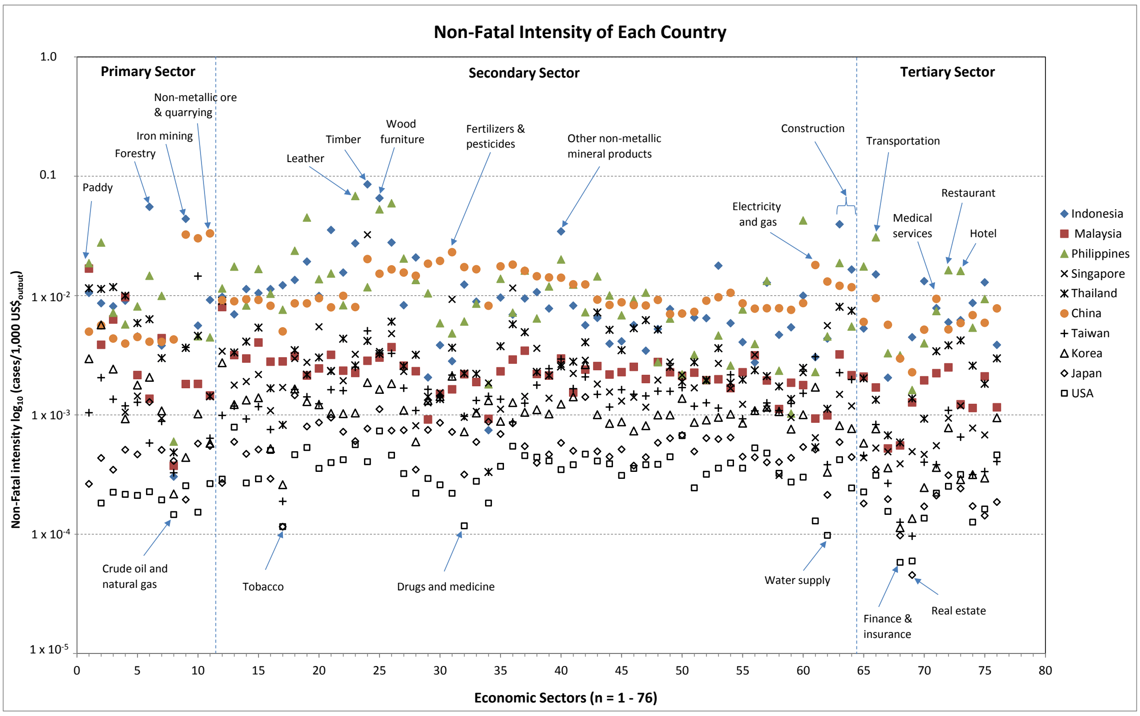

Figure 5-11. Comparison the non-fatal occupational intensity from cradle to gate of 10 countries by economic sector.

5.3.5.2 Non-fatal occupational injuries footprint per capita

Figure 5-12 shows the results of the non-fatal occupational injuries footprint per capita, based on the final demand of each country. The results showed that Indonesia has the highest non-fatal footprint per capita (1.49×10^{-2} case), followed by Japan (1.41×10^{-2} case), USA

(1.32×10^{-2} case), the Philippines (1.30×10^{-2} case), Singapore (1.28×10^{-2} case), Taiwan (1.22×10^{-2} case), China (1.19×10^{-2} case), and Korea (1.14×10^{-2} case). On the other hand, Malaysia has the lowest non-fatal footprint per capita (8.39×10^{-3} case), followed by Thailand (8.57×10^{-3} case). If we consider the case of Thailand, the non-fatal footprint is about 8.57×10^{-3} cases per capita, whereas, in the USA and Japan, the non-fatal footprint is estimated at about 1.54 and 1.65 times that of the Thai people, respectively.

The non-fatal footprints are associated with intra-country and inter-country trading. The majority of non-fatal footprints is associated with importing goods from the developing countries to the developed countries; imports from China to Japan, South Korea, Taiwan, USA, Singapore, and Malaysia correspond to 58%, 57%, 51%, 49%, 43% and 32% of total non-fatal embodied in trade, respectively. While, imports from China to Thailand, Indonesia, and the Philippines correspond to 15%, 3%, and 2% of total non-fatal incidents, respectively. However, the domestic non-fatal footprints of each country are included the effect of imported from the RoW based on assumptions in the section 5.2.3.

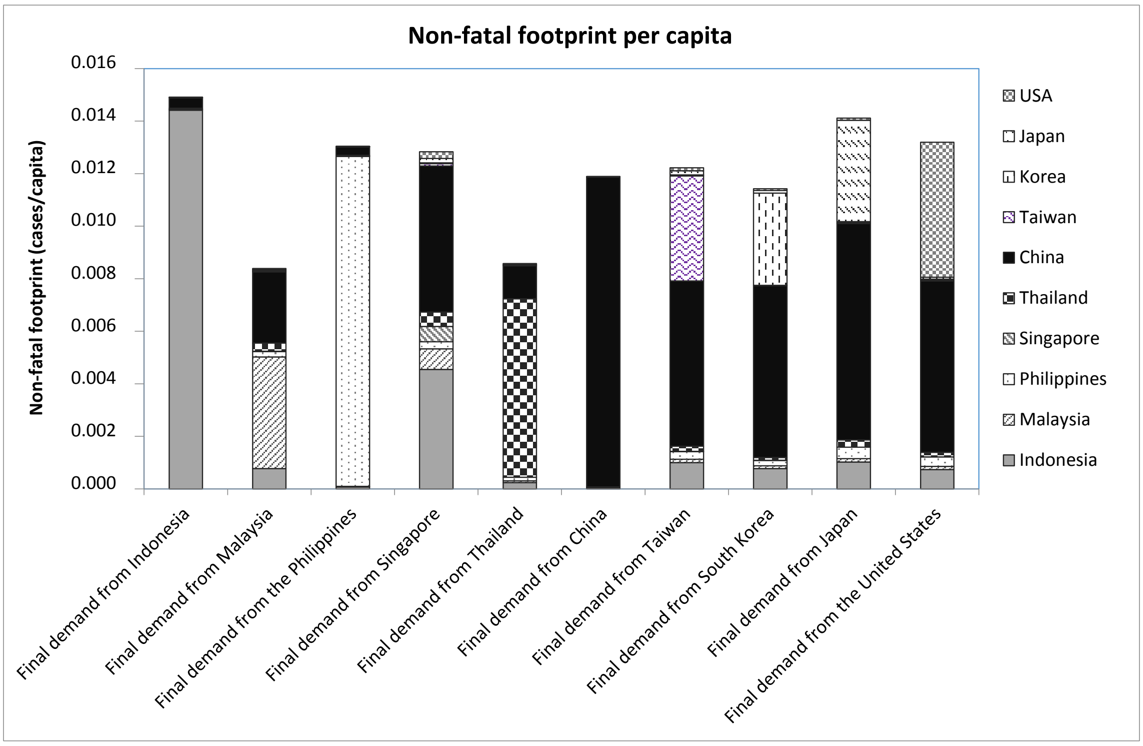

Figure 5-12. Comparison the non-fatal occupational injuries footprint per capita for each country.

5.3.6 Fatal occupational injury

5.3.6.1 Fatal occupational injury intensity

The fatal occupational injury intensity, expressed in terms of cases per 1000 US$ output of 10 countries with 76 industrial sectors, is presented in Figure 5-13. The fatal intensity is the highest in the developing countries as follows: China, Indonesia, Philippines, Thailand, and Malaysia, respectively. On the other hand, the developed countries (USA and Japan) had lower fatal intensities than that of the developing countries. Whereas, countries with a medium fatal intensity are Singapore, Taiwan, and South Korea. The fatal occupational injury intensity obtained in our study demonstrated similar trends to the results obtained by Simas et al. [19].

When considering the primary sector (IO code 1–11), the fatal intensity of the mining sector is higher than other sectors in almost all countries, especially in the developing countries. The mining sector in China has the highest fatal intensity compared to other countries and other primary sectors. While the lowest fatal intensity is the crude oil and natural gas sector in almost all countries. In the case of Thailand, the fatal intensity is the highest in the non-metallic ore and quarrying sector (5.77×10^{-5} case/1000 US$), followed by the forestry sector (2.93×10^{-5} case/1000 US$) and the livestock sector (1.90×10^{-5} case/1000 US$). In addition, the agricultural sector (including forestry and fishery) is one of the three most hazardous areas to work along with mining and construction [46]. The intensive use of machinery and agrochemicals boosts the risks. Comparing the health and safety levels in agricultural work between countries is difficult; therefore, the absolute number of workplace accidents in agriculture is misleading as there are many factors related to accidents, especially in relation to the measure of exposure, such as working hours or the number of workers. The official data on the incidence of workplace accidents are imprecise and tend to underestimate actual rates in agriculture, particularly in developing countries as the agricultural sector in developing countries is dominated by small scale farming.

When considering the fatal intensity of the secondary sector (IO code 12–64), the results showed that China has a higher fatal intensity than other countries in almost all sectors. The top five fatal intensities in China are the chemical fertilizers and pesticides (1.15×10^{-4} case/1000 US$), electricity and gas ($1.10\times10^{-4}$ case/1000 US$), building construction (1.05×10^{-4} case/1000 US$), other construction ($1.03\times10^{-4}$ case/1000 US$), and basic chemicals sector (8.65×10^{-5} case/1000 US$). For Malaysia, the top-ranked fatal workplace intensities are the building construction (2.33×10^{-5} case/1000 US$), other food products ($2.12\times 10^{-5}$ case/1000 US$), other construction ($1.46\times10^{-5}$ case/1000 US$), wearing apparel ($1.35\times 10^{-5}$ case/1000 US$), and spinning sector ($1.31\times10^{-5}$ case/1000 US$). For the Philippines, these are the leather products (1.39×10^{-4} case/1000 US$), building construction (1.19×10^{-4} case/1000 US$), and other manufacturing products (1.04×10^{-4} case/1000 US$). In Thailand, the top five fatal intensities are in the other construction (6.35×10^{-5} case/1000 US$), building construction (6.34×10^{-5} case/1000 US$), chemical fertilizers and pesticides (5.78×10^{-5} case/1000 US$), timber (5.63×10^{-5} case/1000 US$), and cement and cement products sectors (4.25×10^{-5} case/1000 US$). For the majority of these sectors, fatal workplace accidents may be traced back to the supply chain. While, the fatal intensity of the USA is low in comparison with other countries, followed by Japan.

For the tertiary sector (IO code 65–76), the general understanding is that the workers in these sectors are at low risk of occupational injury and death. However, these workers are involved in a wide range of working activities and are exposed to a variety of risks. Occupational fatalities with the highest intensity were found in the transportation sector in almost all countries. The top-ranked fatal intensity of the transportation sector is the Philippines (5.89×10^{-5} case/1000 US$), Indonesia (5.63×10^{-5} case/1000 US$), China (4.89×10^{-5} case/1000 US$), Thailand (2.83×10^{-5} case/1000 US$), and Malaysia (2.06×10^{-5} case/1000 US$), respectively. These values are about 10–30 times higher than that of developed countries and the richest Asian countries.

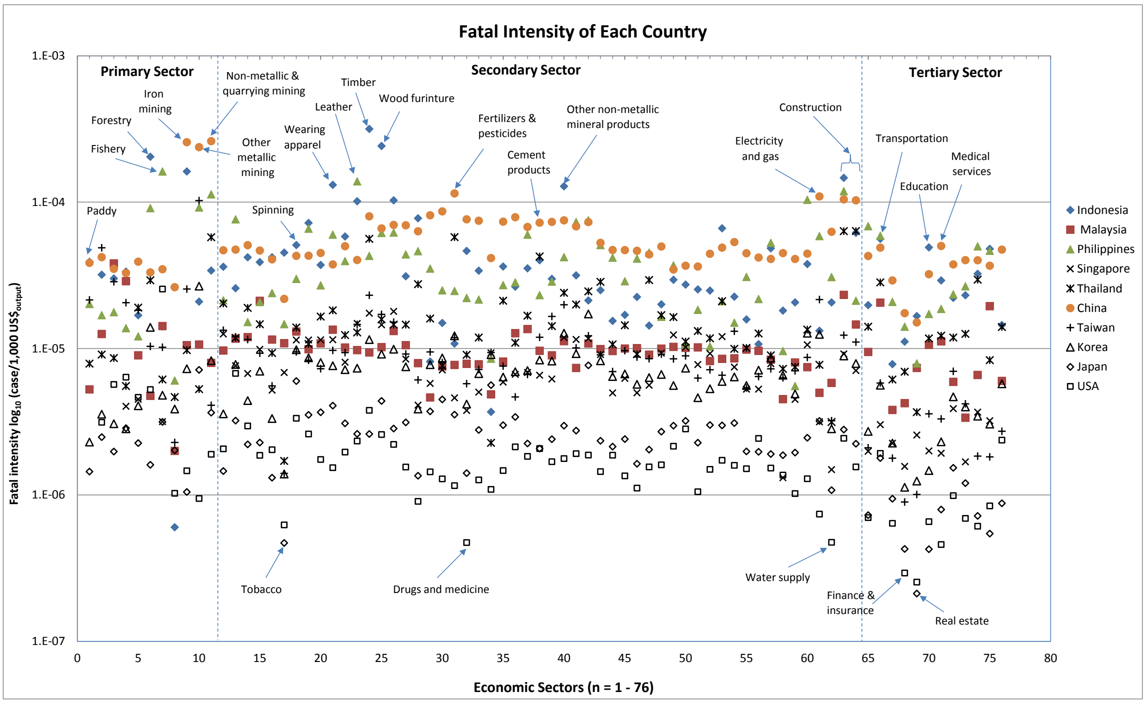

Figure 5-13. Comparison the fatal occupational intensity from cradle to gate of 10 countries by economic sector.

5.3.6.2 Fatal occupational injury footprint per capita

The results of the fatal occupational injury footprint per capita is based on final consumption of 10 countries and are presented in Figure 5-14. The results show that China has the highest fatal footprint per capita (8.11×10^{-5} case), followed by South Korea (7.99×10^{-5} case), Taiwan (7.66×10^{-5} case), Japan (6.73×10^{-5} case), Singapore (6.53×10^{-5} case), and USA (6.14×10^{-5} case). On the other hand, Malaysia has the lowest fatal footprint per capita (4.57×10^{-5} case), followed by Thailand (4.65×10^{-5} case), the Philippines (4.96×10^{-5} case), and Indonesia (5.60×10^{-5} case). If we consider the case of Thailand, the fatal footprint is approximately 4.65×10^{-5} cases per capita, whereas the USA and Japan had a fatal footprint estimated of 1.32 and 1.45 times that of Thai people, respectively.

The fatal footprint is associated with intra-country and inter-country trade. The majority of fatal footprints is associated with exchanges of goods and services from the developing countries to the developed countries; exchanges from China to Japan, USA, South Korea, Taiwan, and Singapore correspond for 68%, 54%, 49%, 49% and 46% of total fatality embodied in trade, respectively. While, exchanges from China to Malaysia, Thailand, Indonesia, and Philippines correspond to 32%, 15%, 4%, and 3% of total fatality embodied in trade, respectively. China is obviously the world's largest exporter, being the primary exporter to the other nine countries. However, the domestic fatal footprints of each country are included the effect of imported from the RoW based on assumptions in the section 5.2.3.

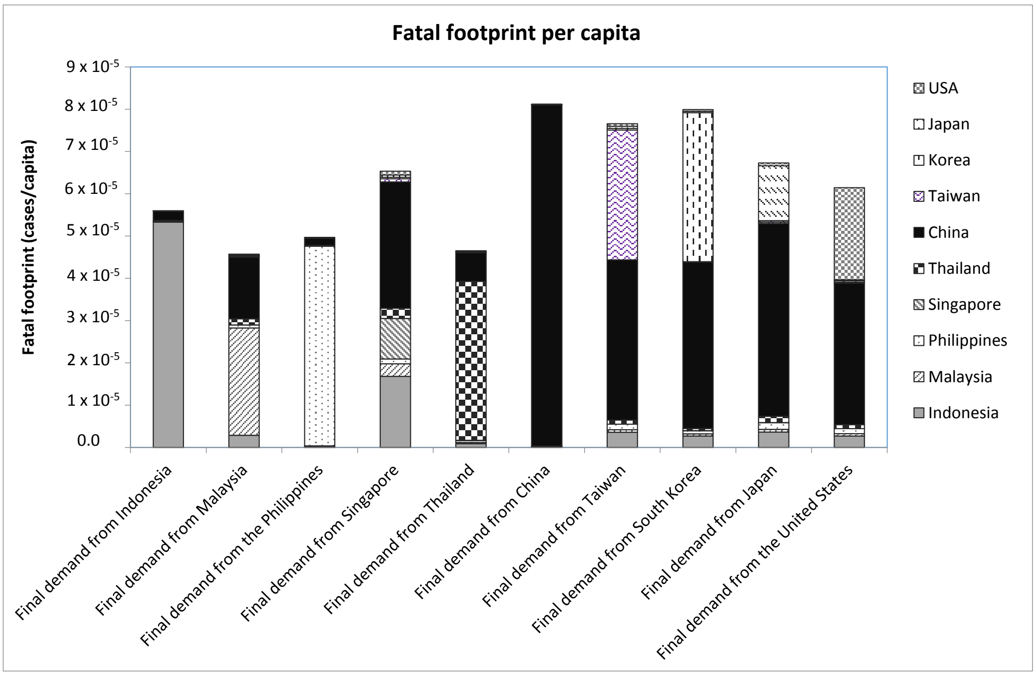

Figure 5-14. Comparison the fatal occupational injuries footprint per capita for each country.

5.4 Discussions

Labor intensity of each industrial sector was calculated by the ratio of employment to the monetary output of that sector. When comparing the capital-intensive and labor-intensive industries, the labor intensity of labor-intensive industries will use many more workers than those capital-intensive industries producing the same value of output. Based on the total employment, paid workers, and vulnerable employment intensity, the developing countries are labor intensive while the developed countries are capital-intensive. In addition, we found that the agricultural, textiles and garment, wood products, construction, wholesale and retail trade, hotel, and restaurant sectors are labor intensive when comparing them with other economic sectors. Our results are similar to previous studies [6,19,20,21,46].

Generally, more advanced technology implies higher wages and safety, but lower labor inputs. However, it is guessed that the manufacturing in developed countries, such as the USA and Japan, requires less labor input with high wages and greater safety than in developing countries such as China, Indonesia, Philippines, etc. On the other hand, people in developed countries normally consume more resources and produce a greater footprint than those in developing countries. The results of our study proved this. In the case of China, in the primary sector, China needs about 13–65 times more labor than the USA to produce the same value of exports. For the secondary sector, China requires about 6–60 times more labor than the USA to produce the same value. While, in the tertiary sector, China needs about 11–25 times more labor than the USA to produce the same value. Based on final demand of China's consumption, the employment per capita of Chinese people is less than that of the American people. In the case of Thailand, in the primary sector, Thailand requires approximately 3–60 times more labor than in the USA to produce the same value of exports, whereas, in the secondary sector, Thailand requires approximately 2–42 times more labor than the USA to produce the same value. While, in the tertiary sector, Thailand requires approximately 5–30 times more labor than in the USA to produce the same value. When comparing the footprint of total employment and vulnerable employment per capita between the developed countries and developing countries, the results showed that both footprints in the developed countries were higher than that of the developing countries. Our results are similar to previous studies [19]. In addition, this study's results showed that more than 16% of the employed workers in 10 countries for consumption in a country other than their own. China is obviously the world's greatest exporter, being the major exporter to six of the nine countries. We can find that the total income received by Chinese workers is very high when compared with workers in the Philippines or Indonesia.

Normally, the agricultural sector in the developing countries is of a higher intensity in total employment, vulnerable employment, fatalities, and non-fatal injuries, yet low in wages. Agriculture in the developing countries occurs in a small scale, while in the developed countries it is usually performed on an industrial scale. This result is similar to the previous study conducted by Papong et al. [21]. A particular attribute of the agricultural sector is the lack of a clear-cut division between different groups of workers. For example, during harvesting periods, many smallholder farmers in developing countries supplement their income by working on large commercial farms. Working conditions and labor relations of permanent and temporary workers are very different. Permanent workers receive job security, higher wages, and health and work benefits. However, work in agriculture is mostly carried out by daily laborers, seasonal laborers and temporary workers who are low-skilled and perform under poor working conditions. Normally, this labor relates to family workers. There are inequalities in the economic development of different countries; for example, a developing country is characterized by low-skilled farming which takes up a large proportion of labor in rural areas. Whilst in developed countries, skilled farmers use highly mechanized processes and, therefore, achieve higher productivity by using a few workers.

The mining sector in the developing countries is characterized likewise by high employment, fatal, and non-fatal injuries intensities. While, in developed countries, mining is indicated by high fatal, high non-fatal injuries and high wage intensities but low employment. The secondary and tertiary sectors in the developing countries showed similarities in high employment, fatal, and non-fatal injuries intensities but low intensity in income. While, in developed countries, these sectors are defined by low employment, fatal, non-fatal injuries but high wages.

5.4.1 Policy implications

The developing countries such as China, Indonesia, etc., normally have lower regulations on labor, health, and safety than developed countries. The shift of manufacturing being centered in developed to developing countries has partially contributed to this. Clearly, the developed countries have gained from the trade with developing countries in terms of reducing their resource consumption, worker consumption, and rate of fatal and non-fatal injuries, while products are cheap. Because of this, vulnerable employment, fatal and non-fatal injuries intensities in the developing countries are higher than those in the developed countries. While, paid worker and labor income intensities in the developed countries are higher than those in the developing countries. All countries might reconsider the trade-offs they are making if using the information on embodied social impacts of trade when conducting negotiations. In addition, this study of labor embodied in trade is also helpful for domestic policy-making, particularly in the developing countries. This study obviously shows that labor input and occupational health impacts in the developing countries are concentrated in manufacturing and not domestic consumption. Thus, worker consumption and occupational health and safety impacts in the manufacturing phase are crucial for improving standards in developing countries.

5.4.2 Sensitivity analysis

5.4.2.1 Assumption change effect on fatal injury intensity of Japan

Estimation of fatal intensity in the manufacturing sector of Japan based on the disaggregated original data by employment share of each sector (S0) is averaging 2.56×10^{-6} cases/1000 US$, and that of estimated using the fatality rate of USA (S1) is averaging 2.63×10^{-6} cases/1000 US$. The difference of the estimation between the two scenarios showed 2.7%. The results of the sensitivity analysis done for two scenarios effect on the fatal intensity are shown in Figure 5-15. The result presented as percentages relative to the base case scenario (S0). The assumption change based on (S1) was the significant effect in 8 sectors of total 49 sectors including the milled grain and flour, fish products, clothing products, leather and leather products, timber, wooden furniture, cement and cement products, and other non-metallic mineral products. These sectors show some significant differences between Japan and USA. While the rest 41 sectors, a similarity situation is observed: insignificant effects on the fatal intensity of changes of assumption as S1. Since the fatal rate of these sectors in Japan is similar to the USA, the impact of S1 on the 41 sectors are not so significant in this analysis. It is recommended that the estimate of the fatal accident of each sector by disaggregated original data based on the employment share of each sector can make it possible to provide reliable data. Due to we do not have sufficient information to distribute the fatal cases across all economic sectors in each country.

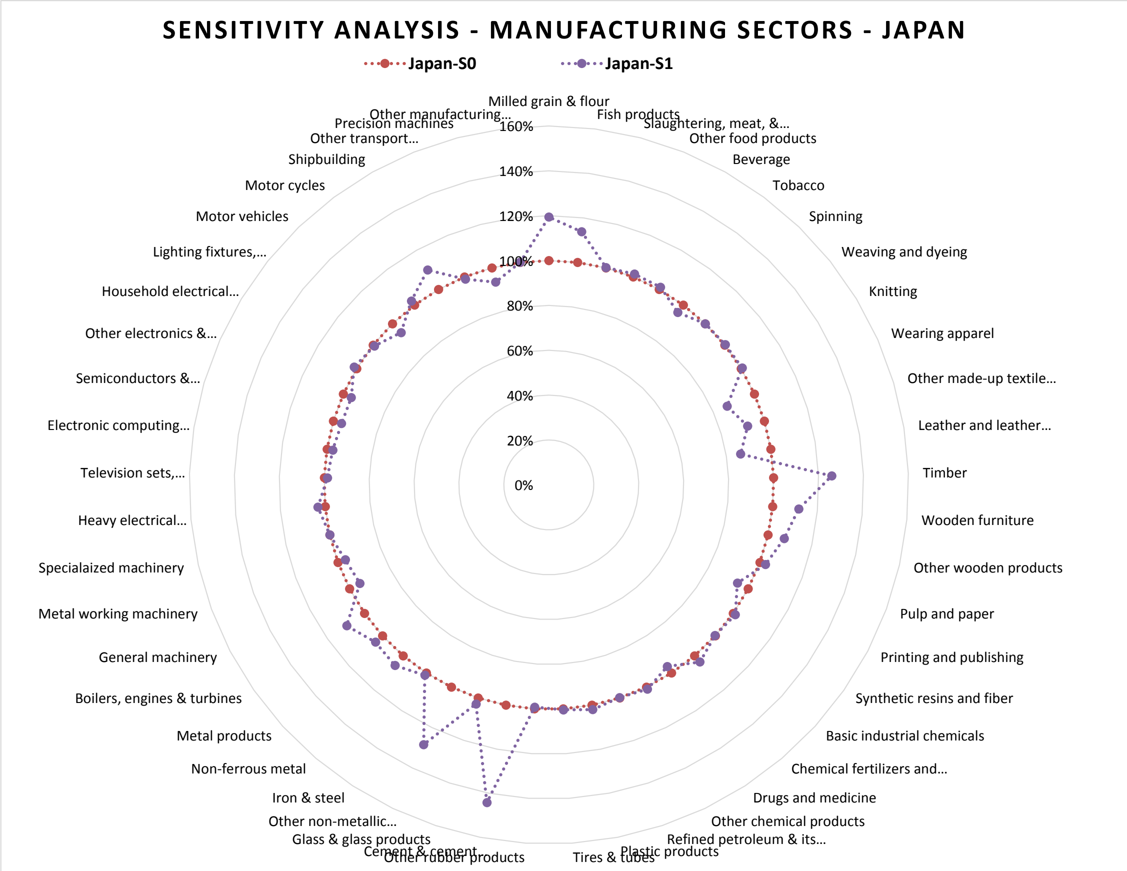

Figure 5-15. Sensitivity analysis of the fatal occupational intensity for Japan.

5.4.2.2 Assumption change effect on fatal injury intensity of Indonesia

In order to evaluate the impact of changes of calculation assumption on the fatal injury in the manufacturing sector of Indonesia, taking into consideration the sensitivity analysis were carried out as following:

- Base case scenario (S0): the proportion of workers with fatal injuries of each sector in 2005 would be as same as the statistical data in the year 2009, and disaggregate original data by employment share of each sector based on assumption that the proportion of workers with injuries would be same as for sub-sector under major sector.
- Scenario 1 (S1): estimation the missing data in the manufacturing sector of Indonesia by using the fatal rate of the manufacturing sector in the Philippines.
- Scenario 2 (S2): estimation the missing data in the manufacturing sector of Indonesia by using the fatal rate of the manufacturing sector of Indonesia in the year 1997.

The results of the sensitivity analysis done for three scenarios effect on the fatal intensity of Indonesia are presented in Figure 5-16. This result displayed as percentages relative to the base case scenario (S0). The average difference of the estimation between the S0/S1 and S0/S2 scenarios showed 1.1% and 3.2%, respectively. It can be verified that among the studied variables, the one which presents the most significant impact on the fatal injury of Indonesia is the calculation assumptions. The assumption change based on (S1) was the significant effect in 9 sectors of total 49 sectors, such as the other food products, spinning, weaving and dyeing, etc. While, the assumption change based on (S2) was the significant effect in 17 sectors of total 49 sectors, such as the other food products, tobacco, spinning, weaving and dyeing, other non-metallic mineral products, household electrical equipment, etc. It is recommended that the estimate of the fatal accident of each sector based on the S0 can make it possible to provide reliable data at this time. Due to we do not have sufficient information to estimate the fatal cases across all economic sectors in Indonesia.

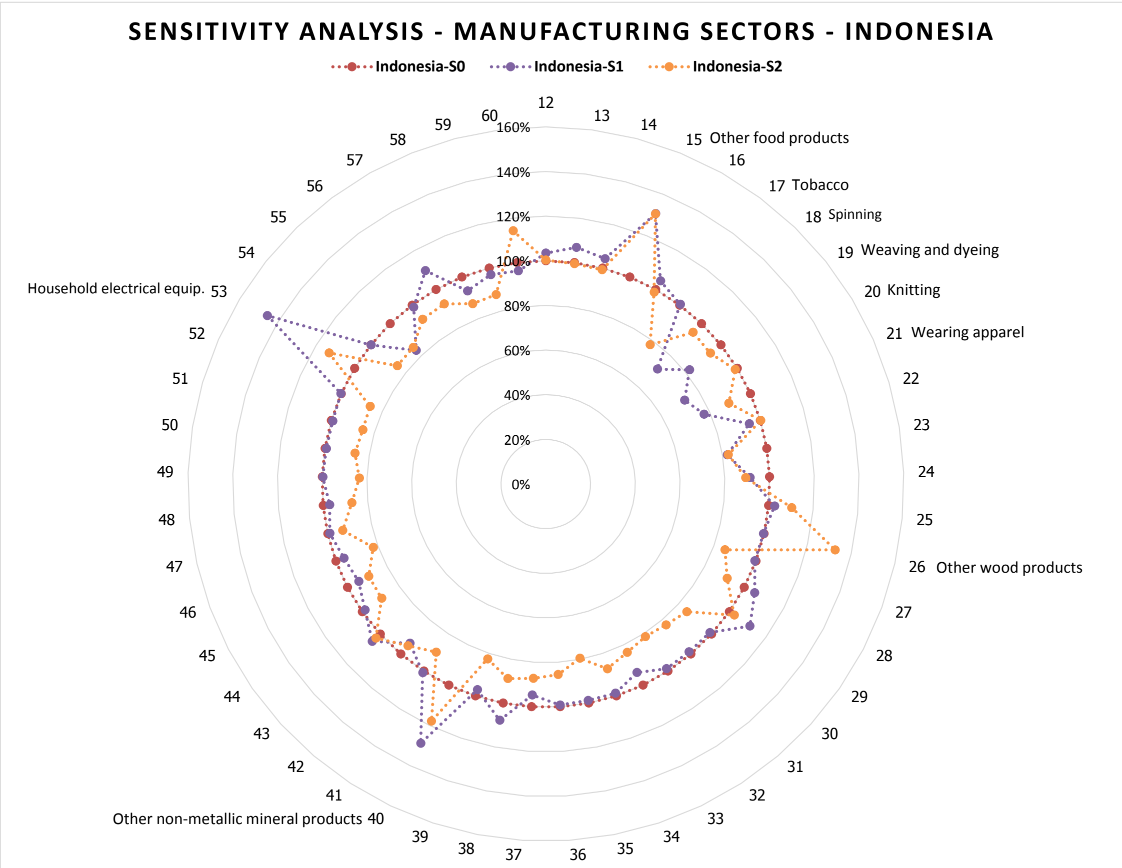

Figure 5-16. Sensitivity analysis of the fatal occupational intensity for Indonesia.

5.4.2.3 Fatal rate change effect on fatal injury intensity of China

In order to evaluate the impact of changes of the fatality rate on the fatal intensity in the manufacturing sector of China, taking into consideration the sensitivity analysis was carried out as follows:

- Base case scenario (S0): the fatality rate of each industrial sector in 2005 of China gathered from the National Profile Report on Occupational Safety and Health in China (ILO, 2012).
- Scenario 1 (S1): changes of +10% fatality rate of sub-sector in the manufacturing sector on the fatal intensity of China.
- Scenario 2 (S2): changes of +20% fatality rate of sub-sector in the manufacturing sector on the fatal intensity of China.

The results of the sensitivity analysis done for three scenarios effect on the fatal intensity of China are presented in Figure 5-17. This result displayed as percentages relative to the base case scenario (S0). It can be verified that among the studied variables, the one which presents the most significant impact on the fatal intensity of China: variation of +20% fatality rate change causes the large changes in the fatal intensity in all the scenarios evaluated at the average value of 10.2%. Changes of +10% on the fatality rate also affect the fatal intensity of China, but with less intensity than the +20% fatality rate change.

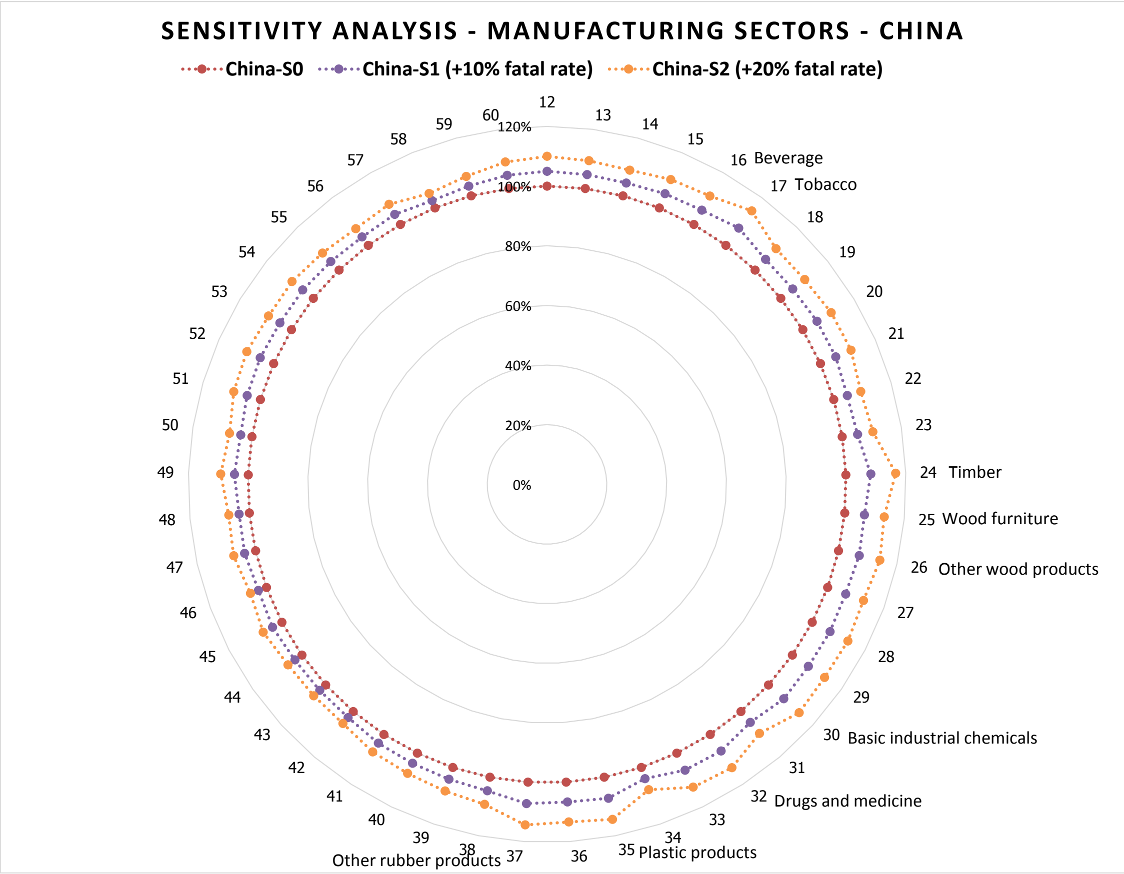

Figure 5-17. Sensitivity analysis of the fatal occupational intensity for China.

The results of sensitivity analysis of the fatal occupational intensity, the most important parameter effect on the fatal intensity is the changes of +20% fatality rate of sub-sector in the manufacturing sector of China. The next important parameter is the estimation the missing data in the manufacturing sector of Indonesia using the fatal rate of Indonesia in the year 1997, followed by the estimation the missing data in the manufacturing sector of Indonesia using the fatal rate of the Philippines, respectively.

5.4.2.4 Change in the type of database and country difference on the employment intensity and employment footprint

In order to evaluate the impact of changes of the type of database and country difference on the employment intensity of Thailand and the employment footprint of Thailand, Malaysia, China, Japan and USA, taking into consideration the sensitivity analysis were performed as follows:

- Base case scenario (AIIO): evaluate the employment intensity and employment footprint using the AIIO table, included 10 countries and 76 sectors.
- Scenario 1 (ADB MRIO): evaluate the employment intensity and employment footprint using the Asian Development Bank MRIO table (extended from with the World IO Database (WIOD) table), included 45 countries and 35 sectors.

The results of the sensitivity analysis done for two scenarios effect on the employment intensity of Thailand are shown in Figure 5-18. This result presented as percentages relative to the base case scenario (AIIO). It can be verified that the ADB MRIO presents the high significant impact on the employment intensity of Thailand in 6 sectors of total 34 sectors, including the (8) coke and refined petroleum products, (6) wood and products of wood, (4) textiles and textile products, (17) electricity, gas and water supply, (24) air transport, and (34) private households with employed persons. The ADB MRIO dataset has led to an investigation of the validity, comparability, uncertainty of the AIIO dataset. Due to different sectoral, country and temporal resolution, different databases are suitable for different analyses. AIIO database has usually only 10 countries which small region model and assuming that labor use of the rest of the world (RoW) are identical to those of Asian industries can introduce an error into the labor embodied in the commodities produced and international trade. On the other hand, the ADB MRIO database has more detailed which covered 45 countries and RoW, thus is better suited for analyzing in high resolution and reducing the error effect. For example, the coke and refined petroleum products sector in Thailand used the raw material (crude oil) from domestic

(15%) and imported from the middle-east (65%) and other countries included Asian countries (20%) (DEDE, 2006), the result showed that the ADB MRIO had higher accuracy than the AIIO database. Thus, the RoW in the ADB MRIO database has an influence on the employment intensity in the coke and refined petroleum products sector in Thailand about 2.75 times in comparison with the AIIO database. While, in the wood and products of wood sector was imports of logs and sawn timber from Malaysia, Myanmar, Laos, USA, New Zealand, EU, and other (Royal Forest Department, 2016). The RoW in the ADB MRIO database has an influence on the employment intensity in the wood and products of wood sector about 1.75 times when comparing the AIIO table.

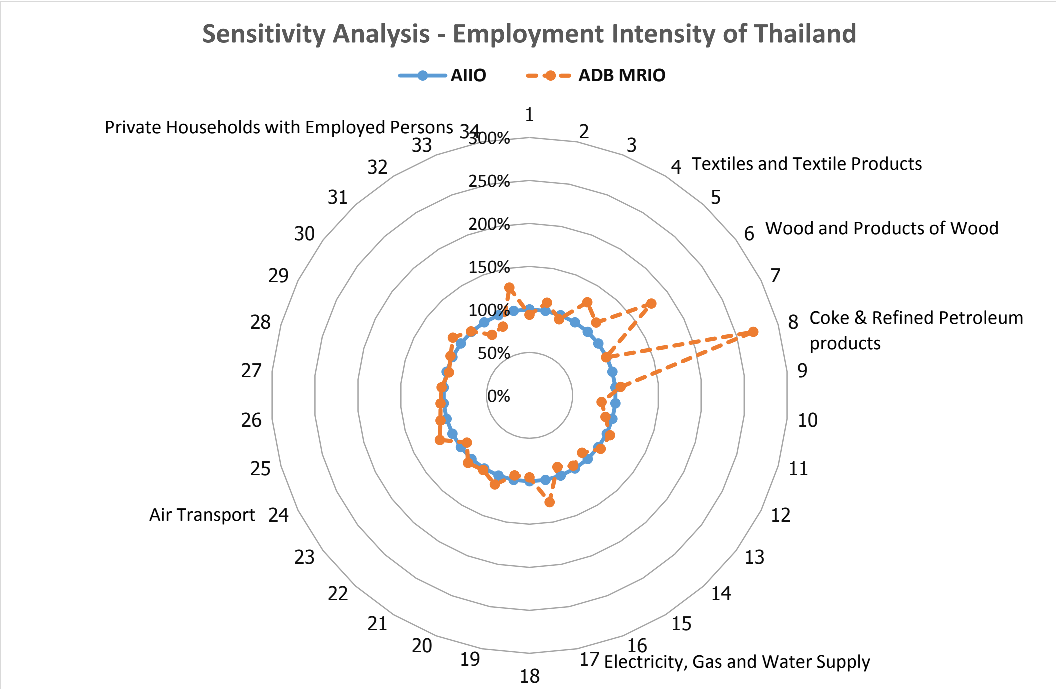

Figure 5-18. Sensitivity analysis of the employment intensity for Thailand.

In addition, we can be analyzed the sensitivity effect of the type of database and country difference on the employment footprint of Thailand, Malaysia, China, Japan, and the USA as presented in Figure 5-19. This result showed the employment per capita of each country using the AIIO table in comparison with the ADB MRIO. It can be found that the ADB MRIO presents the high significant impact on the employment footprint of the USA due to the high contribution import from the rest of the world. Based on the ADB MRIO model, to satisfy the final demand of the USA, one American people require nine-tenths of one worker to support their lifestyle. This consists of domestic workers (54.9%) and foreign workers (China 17.7%, other Asian countries 4.4%, India 6.8%, and other RoW 16.2%). For one Japanese person needs eight-tenths of one worker to sustain their standard of living, which comes from the domestic (58.3%) and foreign workforce (China 20.4%, other Asian countries 7.3%, India 2.5%, and other RoW 11.5%).

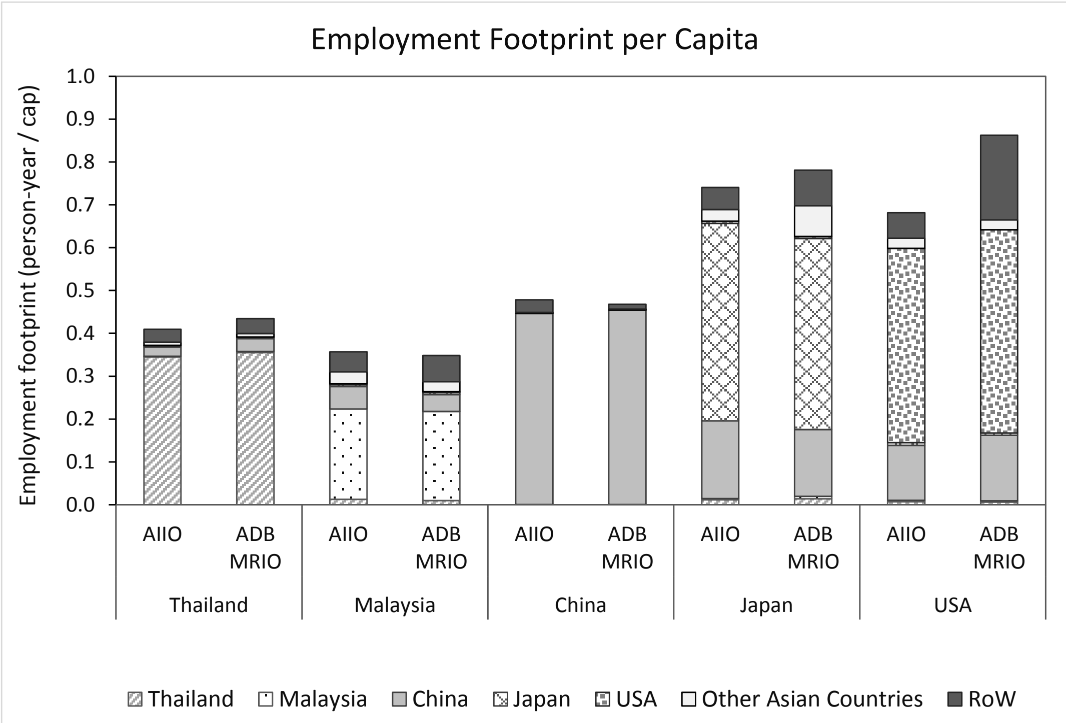

Figure 5-19. Sensitivity analysis of the employment footprint for Thailand, Malaysia, China, Japan, and the USA.

5.4.3 Uncertainties of the study

The normal uncertainties of the IOA method include aggregation, time delays, hypothesis of the linear inter-sector relationships, and homogeneity of products. Even though uncertainty analysis from these viewpoints is carefully done first because of the lack of data within input–output tables, in this study, the uncertainties will focus on the variation between the 10 countries, trade data, and the estimation of labor, fatal and non-fatal injuries consumption. The 10 countries are different in terms of various variables, such as population number, development stage, and policies and regulations, which significantly affect the occupational health impacts embodied in trade. For example, the large population of China affects the higher labor intensity of the economic sector in China. In addition, policies and regulations on employment and occupational health and safety in the developing countries and developed countries are significantly different. Uncertainties also come from a lack of statistical data for some countries. In particular, using the official data on fatal and non-fatal injuries reported by national and international organizations can change the results on fatal and non-fatal injuries embodied in trade. It is estimated that 50% of the labor force in the developing countries work in the informal market [47]. This study has estimated the data of non-fatal and fatal injuries from the informal market by adjusting the national statistics of each country.

5.5 Comparison the labor database from various data sources

A comparison has been performed to investigate the variations of data from different data sources using this study and other studies. Table 5-3 to Table 5-5 show the employment database of various data sources for Thailand, Japan, and USA, respectively. These datasets show that the number of employment in some industrial sectors are quite different among different data sources. Due to the different methods use to estimate the employment in each dataset. If we focused on the mining and quarrying sector in Thailand, the result shows that the employment of the Eora MRIO database is very higher than the AIIO and THIO because the Eora MRIO was estimated the labors based on the national daily minimum wage rate in Thailand whereas the AIIO and THIO database calculated based on the labor force survey of the National Statistical Office of Thailand. The daily minimum wage rates in Thailand were based on the unskilled workers, however, the labors in mining and quarrying sector are the medium and high skilled workers which their wage levels are very higher than unskilled workers. It is recommended that the estimate of the employment of each industrial sector should be used the pay month rate of each sector by instead the daily minimum wage rate, which it possible to provide reliable data.

Table 5-3. The employment database of Thailand from different data sources.

Thailand	AIIO[1]	THIO[2]	Eora MRIO[3]
Agriculture, Hunting, Forestry and Fishing	13,844,972	13,679,668	15,488,328
Mining and Quarrying	52,124	61,116	358,058
Food, Beverages and Tobacco	985,447	1,045,967	870,066
Textiles and Textile Products	1,034,524	1,063,707	1,195,696
Leather, Leather and Footwear	163,368	164,256	183,072
Wood and Products of Wood and Cork	272,111	272,111	409,433
Pulp, Paper, Paper , Printing and Publishing	203,017	212,033	297,211
Coke, Refined Petroleum and Nuclear Fuel	8,194	17,351	45,346
Chemicals and Chemical Products	206,279	203,909	549,462
Rubber and Plastics	360,354	354,607	66,356
Other Non-Metallic Mineral	244,860	256,695	834,528
Basic Metals and Fabricated Metal	484,392	417,996	105,666
Machinery	220,941	142,631	170,073
Electrical and Optical Equipment	643,044	577,449	681,251
Transport Equipment	251,402	564,308	438,115

Other Manufacturing and Recycling	258,282	359,457	247,630
Electricity, Gas and Water Supply	80,472	115,843	427,691
Construction	1,858,269	1,858,269	1,856,782
Other sectors	13,231,285	13,035,964	13,486,822
Total	**34,403,337**	**34,403,336**	**37,711,586**

Sources: [1] IDE-JETRO (2013); [2] NSO (2006); [3] Lenzen et al. (2013)

Table 5-4. The employment database of Japan from different data sources.

Japan	AIIO[1]	WIOD[2]	Eora MRIO[3]
Agriculture, Hunting, Forestry and Fishing	4,830,237	3,343,371	491,993
Mining and Quarrying	34,218	59,393	95,257
Food, Beverages and Tobacco	1,533,767	1,407,269	1,303,086
Textiles and Textile Products	441,299	595,317	441,840
Leather, Leather and Footwear	58,741	55,082	46,672
Wood and Products of Wood and Cork	302,869	377,153	351,027
Pulp, Paper, Paper , Printing and Publishing	923,751	817,802	1,249,060
Coke, Refined Petroleum and Nuclear Fuel	29,173	17,690	99,470
Chemicals and Chemical Products	387,214	421,588	849,980
Rubber and Plastics	654,633	677,127	675,039
Other Non-Metallic Mineral	336,867	356,195	473,217
Basic Metals and Fabricated Metal	1,336,941	1,791,781	1,772,144
Machinery	1,219,075	1,105,762	1,591,616
Electrical and Optical Equipment	1,684,102	1,708,541	2,665,362
Transport Equipment	1,590,958	1,219,034	1,492,257
Other Manufacturing and Recycling	301,388	265,829	306,311
Electricity, Gas and Water Supply	312,611	425,732	1,183,552
Construction	5,629,026	5,573,434	5,781,490
Other sectors	45,093,662	43,698,450	42,991,385
Total	**66,700,532**	**63,916,551**	**63,860,759**

Sources: [1] IDE-JETRO (2013); [2] Timmer et al. (2015); [3] Lenzen et al. (2013)

Table 5-5. The employment database of USA from different data sources.

USA	AIIO[1]	WIOD[2]	Eora MRIO[3]
Agriculture, Hunting, Forestry and Fishing	1,965,000	2,167,343	2,250,174
Mining and Quarrying	639,000	612,369	655,263
Food, Beverages and Tobacco	1,978,000	1,785,532	1,500,130
Textiles and Textile Products	666,000	677,227	515,073
Leather, Leather and Footwear	41,000	42,616	50,282
Wood and Products of Wood and Cork	1,056,000	584,197	432,616
Pulp, Paper, Paper , Printing and Publishing	1,308,000	1,912,728	1,305,526
Coke, Refined Petroleum and Nuclear Fuel	181,000	115,022	177,475
Chemicals and Chemical Products	1,082,000	939,208	1,324,440
Rubber and Plastics	821,000	828,806	966,789
Other Non-Metallic Mineral	541,000	526,095	504,851
Basic Metals and Fabricated Metal	2,012,000	2,032,790	2,125,492
Machinery	1,691,000	1,224,038	1,341,545

Electrical and Optical Equipment	2,444,000	1,926,349	2,310,585
Transport Equipment	4,135,000	1,819,715	2,623,539
Other Manufacturing, and Recycling	635,000	1,019,155	1,198,717
Electricity, Gas and Water Supply	1,456,000	548,144	2,063,059
Construction	9,563,000	9,237,111	10,190,738
Other sectors	113,962,000	120,904,885	110,615,053
Total	**146,176,000**	**148,903,330**	**142,151,349**

Sources: [1] IDE-JETRO (2013); [2] Timmer et al. (2015); [3] Lenzen et al. (2013)

Economic sectors are treated similarly undergoing a process of progressive aggregations until there is an identical sector structure in each IO database. The common classification has 17 sectors. Table 5-6 shows the aggregation for the THIO, AIIO, ADB MRIO, and Eora26. The homogenized version of Eora has a common set of 26 sectors, whereas the full version of Eora the number of sectors per region ranges from 511 to 26. The different IO databases are suitable for different analyses because of different in sectoral, country and temporal resolution. Thailand IO table database has usually a single region and assuming that the RoW are identical to these of Thai industry and more detailed in the agricultural sector, thus is better suited for analyzing in the water and land use footprint. But it can be lead an error into the environmental and social embodied in the commodities produced and international trade. On the other hand, the MRIO databases such as AIIO, WIOD, and Eora database have more detailed which covered many countries and regions, thus are better suited for analyzing in high resolution and reducing the error effect related the international trade.

Table 5-6. Common classification sector aggregation of various IO table databases.

Code	Sector Name	THIO	AIIO	WIOD	Eora26
1	Agriculture, forestry, hunting and fisheries	1-29	1-7	1	1-2
2	Mining and quarrying	30-41	8-11	2	3
3	Food products, beverages and tobacco	42-66	12-17	3	4
4	Textiles, leather and wearing apparel	67-77	18-23	4-5	5
5	Wood, paper and publishing	78-83	24-28	6-7	6
6	Petroleum, chemical and non-metal mineral products	84-103	29-40	8-11	7
7	Metal and metal products	104-111	41-43	12	8
8	Electrical equipment and machinery	112-122, 129-131	44-54, 59	13-14	9
9	Transport equipment	123-128	55-58	15	10
10	Manufacturing and recycling	134-134	60	16	11-12
11	Electricity, gas and water	135-137	61-62	17	13
12	Construction	138-144	63-64	18	14
13	Trade	145-148	65	19-22	15-18

14	Transport	149-158	66	23-26	19
15	Post and telecommunications	159	67	27	20
16	Financial intermediation and business activities	160-164	68-69	28-30	21
17	Public administration, education, health, recreational and other services	165-180	70-76	31-35	22-26

5.6 Comparison the labor intensities by using the THIO and AIIO

5.6.1 Total employment intensity

Comparison has been made to examine the results of total employment intensity of Thailand between using the THIO and AIIO. The Figure 5-20 presents that total employment intensity of almost industrial sectors based on the AIIO were higher than the THIO. Many economic sectors based on the AIIO is very higher than the THIO, such as the iron ore mining, heavy electrical equipment, semiconductors and integrated circuits, iron and steel, etc., due to these sectors are mainly imported from other countries. On the other hand, there are some industrial sectors showed that the THIO is higher than the AIIO because the quite different between the labors database between Thai database and international database.

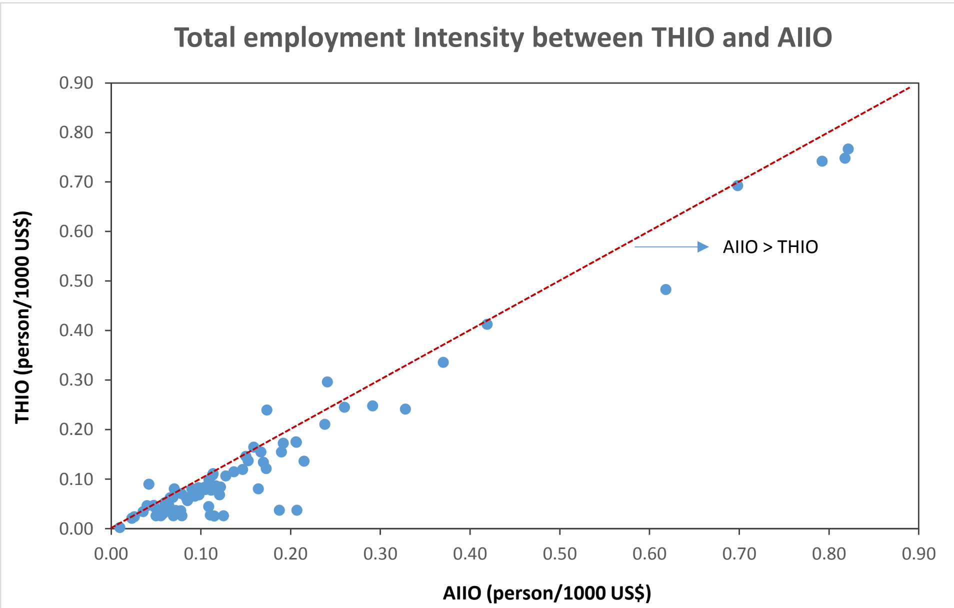

Figure 5-20. Comparison the total employment intensity of Thailand between using the THIO and AIIO.

5.6.2 Wages intensity

Figure 5-21 shows the wages intensity of industrial sectors in Thailand analyzed by using the AIIO and THIO. The result showed that the wages intensities based on the AIIO were very higher than the THIO in almost sectors, especially in the secondary and tertiary sectors. These result come from the wage rates in other countries that imported to Thailand are higher than the wage rates in Thailand.

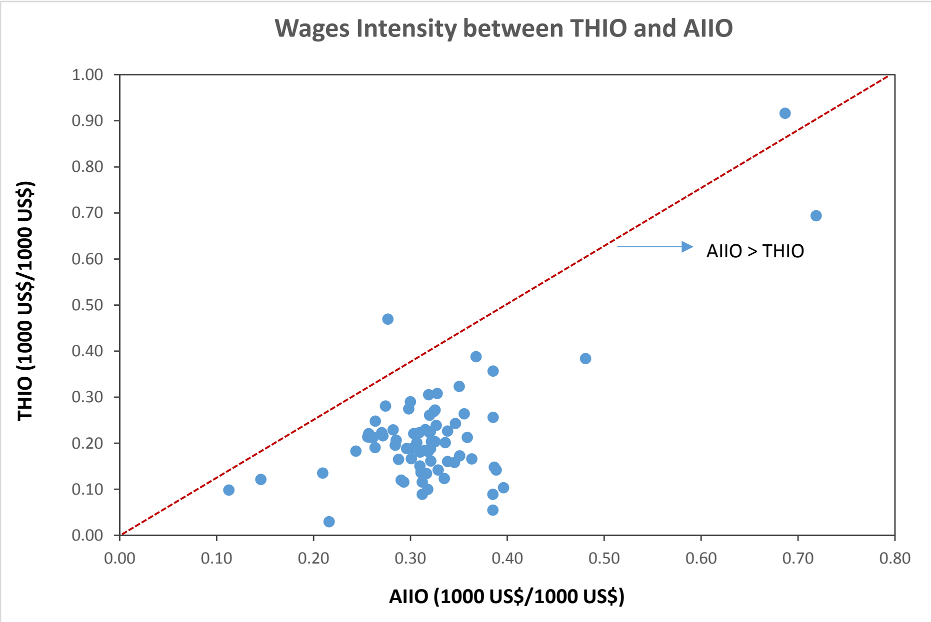

Figure 5-21. Comparison the wages intensity of Thailand between using the THIO and AIIO.

5.6.3 Fatal occupational injury intensity

Comparison has been made to examine the results of the fatal occupational injury intensity of Thailand between using the THIO and AIIO. Figure 5-22 shows that the fatal occupational injury intensity in almost economic sectors based on the AIIO were higher than the THIO. Many economic sectors, the fatal intensity based on the AIIO is very higher than the THIO, such as the special machinery, non-metallic ore and quarrying mining, timber, chemical fertilizers and pesticides, etc., due to these sectors are mainly imported from other countries that high risk work activities.

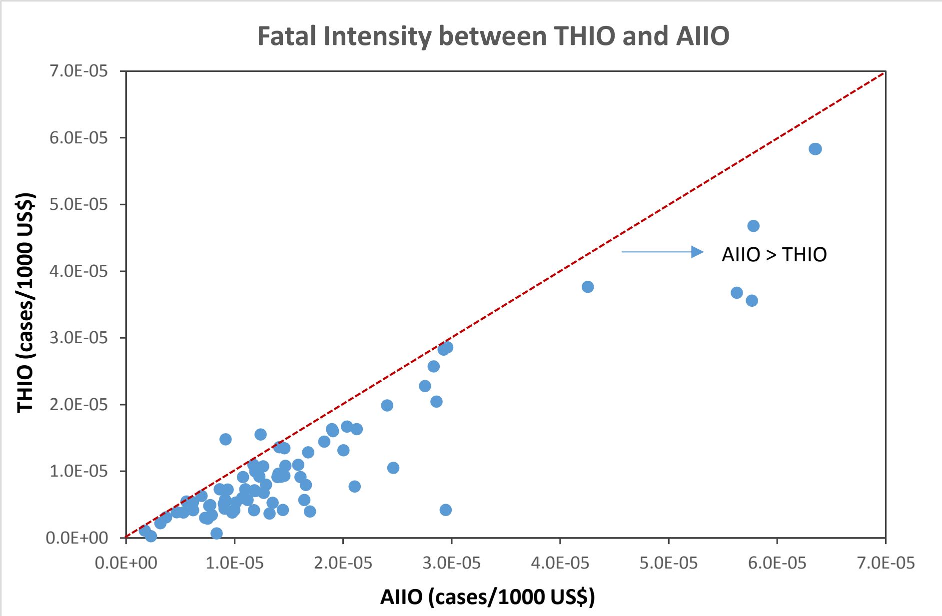

Figure 5-22. Comparison the Fatal occupational injury intensity of Thailand between using the THIO and AIIO.

5.7 Conclusions

5.7.1 Summary

1) This study calculates the social intensity and social footprints associated with the economic sectors of 10 countries and identifies key sectors and important labor issues in Asian countries using the Asian international input–output table. The results show that the labor intensity in terms of total employment, paid workers, vulnerable employment, non-fatal injuries, and fatal accident cases in the developing countries was higher than developed countries, whereas wages intensity in developing countries was lower than that of developed countries.
2) The social footprints are associated with intra-country trade and inter-country trade. The majority of the footprint calculated from total employment, paid workers, vulnerable employment, non-fatal injuries, and fatal cases was associated with exchange of goods and services from the developing countries to developed countries; flows from China to USA, Japan, South Korea, Taiwan, and Singapore have a significant effect on the social impacts embodied in these countries.
3) This study provides information that can assist consumers, producers, and stakeholders to identify social issues of responsibility and encourage better practices across the supply chain. Although the IOA showed in this work is simple to use, some limitations should be considered. Some debatable issues include calculations based on the linear inter-

industry interactions, the estimations of the intensities of the 10 countries, data availability, and data quality.

4) It is not easy to quantify all countries and all sectors of sensitivity analysis in the database. However, in the sensitivity analysis of manufacturing sector focused on the change in calculation assumptions the missing data seem to be important to influence on the fatal intensity accounting in many sectors in Indonesia. Furthermore, polishing of direct fatal intensity in the manufacturing sector, particularly in Indonesia may increase the precision of fatal occupational injury database since the direct fatal intensity is a critical element in the fatal footprint database construction of Indonesia.
5) Based on the sensitivity analysis of the fatal occupational intensity, the most important parameter effect on the fatal intensity is the changes of +20% fatality rate of sub-sector in the manufacturing sector of China. The second important parameter is the estimation the missing data in the manufacturing sector of Indonesia using the fatal rate of Indonesia in the year 1997.

5.7.2 Limitations and further studies

1) It is recommended to use the national database combined with international database and sectoral research papers to estimate the missing data in the fatal and non-fatal occupational injuries for the industrial sectors. Direct fatal and non-fatal injuries estimation are critical in the fatal and non-fatal footprint database construction. The fatal and non-fatal injuries accounting in the developed and developing countries should be done with caution because the fatal and non-fatal injuries of each country are depending on the workplace health and safety regulations, and cultural condition in specific countries.
2) The shortcomings of this study include lack of information on the fatal and non-fatal database in many countries. Direct fatal and non-fatal footprint data by countries may contribute to interest in the accuracy report about the workplace health and safety data of each country in the future.

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Chapter 6. Characterization factor development for the occupational health impact assessment

6.1 Introduction

The impact assessment method in a Social LCA can be categorized into two groups: performance reference point and impact pathways methods as described in Chapter 2. The studies on occupational health and safety impact assessment and other similar evaluation, are increasingly combining the health effects of different occupational health problems. The simple indicator in the calculation is premature mortality with different variations such as the studies of de Hartog et al. (2010) and Rojas et al. (2011). However, the victim's age, that is a key issue when using a premature mortality indicator, have not been taken into account. This may be caused misleading points of view regarding the health burden if different occupations are affecting the population at different ages.

A popular indicator of health is the disability-adjusted life-years (DALY) measure. The DALY method was developed for the Global Burden of Disease studies (Murray et al., 2012) and is a measure of the health-gap comparing the current health and an ideal situation where each person lives a long life without any diseases or disabilities. The DALY calculation has two components: years of life lost due to premature mortality or fatality (YLLs) and years lived disabled or injured (YLDs). The YLLs are calculated by comparing the age of the deceased person to the predicted life-expectancy of a person with same age and gender in that area. YLDs are calculated by multiplying the number of diseases with the disability weight and the duration of that disease. The YLD calculation for occupational injuries needs detailed information of the injury types, disability weight and the duration of injuries. Many studies have proposed the use of the DALY concept to evaluate the health impacts caused by the workplace injuries (Concha-Barrientos et al., 2005; Pettersen and Hertwich, 2008; Polinder et al., 2012; Scanlon et al., 2013; Scanlon et al., 2014; Tainio et al., 2014) or the environmental burden of disease (Devleesschauwer et al., 2014; Yoon et al., 2015; Kobayashi et al., 2015; Gao et al., 2015).

To understand the embodied occupational health impacts of the industrial sector, this study developed the characterization factor for occupational health impact caused by the workplace accidents in Thailand. The occupational health issues included the fatal and non-fatal accidents.

6.2 Methods

To calculate the DALY, this study has used the data on the industry-specific work-related fatal and non-fatal injury and illnesses. For each fatality, the number of years of life lost (YLL) is represented by premature mortality in the worker population and for each nonfatal injury or illness the number of years of life lived with disability (YLD) is represented by the severity of the work-related injury or illness, and its duration. Figure 6-1 shows the framework of occupational health burden of the workplace accident analysis. This study was applied the DALY concept based on WHO suggested (Prüss-Üstün et al, 2003).

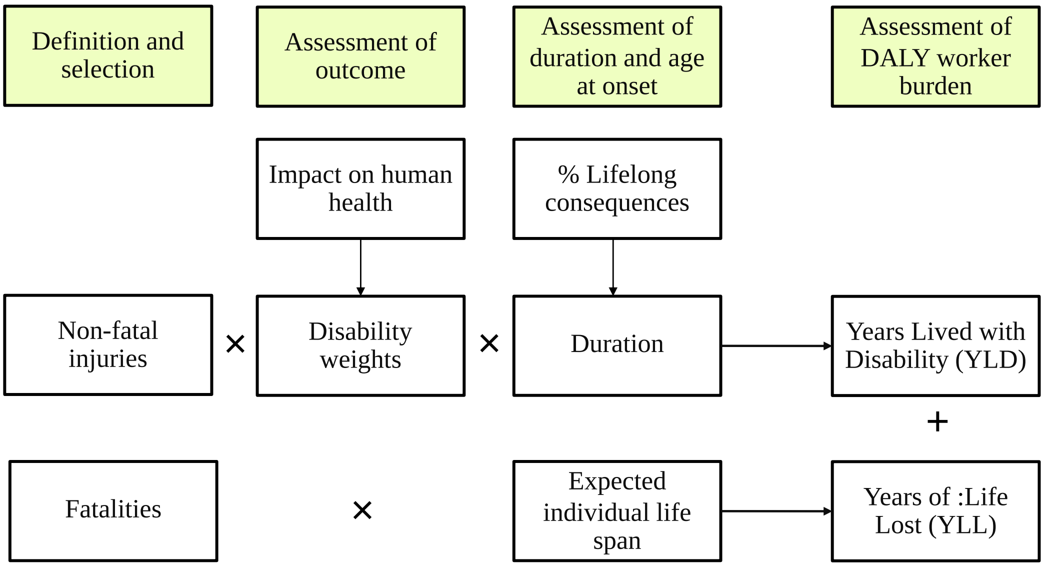

Figure 6-1. Framework of occupational health burden of the workplace accident analysis by using DALY.

The fundamental equation to calculate the DALY is as follows:

$$DALY = YLL + YLD \qquad (6\text{-}1)$$

$$YLL = N \times L \qquad (6\text{-}2)$$

where N is the number of deaths, and L is a standard life expectancy at the age of death (in years).

$$YLD = I \times DW \times L \qquad (6\text{-}3)$$

where I is the number of incident cases, DW is a disability weight, and L is an average duration of disability (years).

The DALY determines the future stream of healthy years of life lost due to each incident case of disease or injury. To estimate the net present value of years of life lost, this study applied a 3% time discount rate to years of life lost in the future based on Lopez et al. (2006). To calculate the DALY is follow:

$$YLL = \frac{N}{r}(1 - e^{-rL}) \tag{6-4}$$

where N is the number of deaths, L is a standard life expectancy at the age of death (years), and r is the discount rate (such as 3% corresponds to a discount rate of 0.03).

$$YLD = \frac{I \times DW \times L(1 - e^{-rL})}{r} \tag{6-5}$$

where I is the number of incident cases, DW is the disability weight, L is the duration of disability (years), and r is the discount rate.

This study applied both an age-weighting and a discounting to calculate the DALY. The simple equation to calculate the YLL and YLD transformed to more complicate as equation (6-6) and (6-7).

Calculation of YLL:

$$YLL = \frac{KCe^{ra}}{(r+\beta)^2}\left[e^{-(r+\beta)(L+a)}\left[-(r+\beta)(L+a)-1\right] - e^{-(r+\beta)a}\left[-(r+\beta)a-1\right]\right] + \frac{1-K}{r}(1 - e^{-rL}) \tag{6-6}$$

where a is the age at death (years), r is the discount rate (usually 3%), β is the age weighting constant (e.g. β=0.04), K is the age-weighting modulation constant (e.g. K=1), C is the adjustment constant for age-weights (e.g. C=0.1658), and L is the standard life expectancy at the age of death (years).

National statistics from the Social Security Office of Thailand (SSO, 2006) reported 808 fatalities for the years 2005. To calculate the YLLs the age and gender of persons who died in workplace accidents were identified and compared to the expected life expectancy.

Calculation of YLD:

$$YLD = DW\{\frac{KCe^{ra}}{(r+\beta)^2}\left[e^{-(r+\beta)(L+a)}\left[-(r+\beta)(L+a)-1\right]-e^{-(r+\beta)a}\left[-(r+\beta)a-1\right]\right]+\frac{1-K}{r}(1-e^{-rL})\} \quad (6\text{-}7)$$

where a is the age of death (years),

r is the discount rate (usually 3%),

C, β, K is the constants (see equation (7-6)),

L is the duration of disability (years),

DW is the disability weight (gathered data from WHO (2004), and Haagsma et al. (2008)).

Duration of time lived with non-fatal injury or illness outcomes

To measure the duration of time lived with non-fatal injury and illness outcomes, the groups of duration time were specified as the life-long and short-term injuries. Life-long injuries and illnesses consequence in the permanent total disability and permanent partial disability. Short-term injuries and illnesses do not consequence in the permanent disability.

The life-long non-fatal injury or illness outcomes, it is assumed that workers live and work with disability outcomes for the remainder of their expected lifetimes. The expected number of years of life remaining is estimated using data from life tables and using a method similar to the YLL calculation.

The short-term non-fatal injury or illness outcomes, it is assumed that workers who had returned to work with temporary disability from the injury or illness. The duration of time lived with temporary disability outcomes is estimated from the median days away from work. Based on Thai data, the median days away from work is transformed into a yearly basis and weighting is based on the assumption that the non-fatal injury or illnesses are suffered by the worker seven days per week (365.2 days per year) substitute of 5.5 work days per week (275 days per year). A conversion factor is estimated for the calendar days in this study as follow:

365.2 days per year / 275 work days per year = 1.33 days (6-8)

The result from equation (6-8) is mean that everyone work day in a year, there are 1.33 calendar days. For example, a worker who suffers a non-fatal injury or illness needing 10 days away from work, in fact suffered the disability associated with the injury or illness as many as

13.3 calendar days. Then, the calendar days is transformed to a year basis by dividing by 365.2. For example, 13.3 days divided by 365.2 days is 0.036; 13.3 days away from work is equivalent to 0.036 years away from work due to a disability resulting from the injury or illness.

6.3 Results and discussions

6.3.1 Years of life lost (YLL)

Burden due to injuries in Thailand, and the DALY rates fatalities due to workplace accidents is 19,637 DALYs per year in 2005 (Table 6-1). Approximately 89% of the DALYs were due to fatalities of male workers and the rest due to fatalities of female workers. The YLL rate for male workers were 4.6 per 1000 employees with an age variation between 3.7 and 7.6 per 1000 employees, whereas YLL rate for female worker were 0.5 per 1000 employees with an age variation between 0.4 and 1.2 per 1000 employees. The average YLLs rate was 2.6 per 1000 employees, whereas an average YLLs per injury was 24.30.

The result of this study is about 25.7% lower than the YLL rates for Global average fatalities in the year 2001 (estimated by Simas et al. (2014) based on data of Concha-Barrientos et al. (2005)). In the Simas et al. (2014) studied, the YLLs per 1000 employees was 3.5, they estimates do not include disabilities resulting injuries which the system boundary is same with this study.

Table 6-1. DALY rate fatalities in the workplace accident in Thailand in the year 2005.

	Number of Employees	**Deaths**	**Deaths per 1,000 employees**	**Av. Age at death**	**Standard LE**	**Disability Weight**	**YLLs**	**YLL per 1,000 employees**
Males								
15-19	104,141	28	0.27	18.1	62.4	1.000	790	7.6
20-24	582,337	101	0.17	22.5	57.9	1.000	2,774	4.8
25-29	903,029	145	0.16	27.5	53.0	1.000	3,848	4.3
30-34	758,275	111	0.15	32.6	48.0	1.000	2,823	3.7
35-39	553,817	96	0.17	37.5	43.1	1.000	2,321	4.2
40-44	387,099	95	0.25	42.6	38.1	1.000	2,157	5.6
45-49	259,212	64	0.25	47.7	33.2	1.000	1,346	5.2
50-54	128,369	48	0.37	52.6	28.5	1.000	920	7.2
55-59	78,347	21	0.27	57.6	23.9	1.000	359	4.6
60-64	26,811	10	0.37	62.7	19.5	1.000	148	5.5
65-69	9,655	4	0.41	67.7	15.4	1.000	49	5.1
70-74	3,979	2	0.50	72.6	11.8	1.000	20	5.0
Total	3,795,072	725	0.19	35.7	45.0		17,554	4.6

Table 6-1. (Continue)

	Number of Employees	Deaths	Deaths per 1,000 employees	Av. Age at death	Standard LE	Disability Weight	YLLs	YLL per 1,000 employees
Females								
15-19	90,559	3	0.03	17.9	65.2	1.000	86	0.9
20-24	686,463	12	0.02	22.6	60.5	1.000	335	0.5
25-29	988,571	17	0.02	27.5	55.7	1.000	460	0.5
30-34	757,425	13	0.02	32.6	50.7	1.000	339	0.4
35-39	544,983	11	0.02	37.5	45.9	1.000	274	0.5
40-44	376,101	11	0.03	42.7	41.0	1.000	259	0.7
45-49	237,888	7	0.03	47.7	36.2	1.000	155	0.6
50-54	102,731	6	0.06	52.6	31.6	1.000	123	1.2
55-59	50,253	2	0.04	57.7	26.9	1.000	37	0.7
60-64	14,289	1	0.07	62.6	22.5	1.000	16	1.1
65-69	5,145	0	0.00	67.6	18.2	1.000	-	0.0
70-74	2,121	0	0.00	72.6	14.1	1.000	-	0.0
Total	3,856,528	83	0.02	35.3	48.2		2,084	0.5
Total	**7,651,600**	**808**	**0.11**				**19,637**	**2.6**
YLLs per injuries							**24.30**	

6.3.2 Years of life lived with disability (YLD)

The DALY rates injuries caused by the workplace accidents is 13,925 DALYs per year in 2005 (Table 6-2 to Table 6-5). The YLDs due to injuries were mainly caused by the permanent partial disability in the workplace accident accounting for 13,372 DALYs (Table 6-3). Of all the injuries, only 1.68% caused partial disability effects, but these partial disability injuries caused 96.03% of the total YLDs.

The YLD rates were 0.061, 1.75, 0.007, and 0.004 DALYs per 1,000 employees for the permanent total disability, permanent partial disability, temporary disability (>3 days), and temporary disability ($\leq$3 days), respectively. The average YLD rate was 1.82 DALYs per 1000 employees. In addition, the average YLDs per injury were 22.23, 3.92, 1.09×10^{-3}, and 1.99×10^{-4}, respectively. The weighted average YLDs per injury was 0.068. If we excluded the temporary disability ($\leq$3 days) in the analysis, the result showed that an average YLDs per injury was 0.25.

The result of YLD rate (1.82 DALYs per 1000 employees) in this study is about 47.4% lower than the YLD rate for non-fatal injuries in the forestry and logging sector in the USA (estimated based on Scanlon et al., 2013). Due to Scanlon et al.'s (2013) analysis, they focused on the non-fatal injuries in the forestry and logging sector, which these being high risk work activities, whereas this study is an average data.

Table 6-2. DALY rate injuries for the permanent total disability in the workplace accident in Thailand in the year 2005.

	Number of Employees	Incidence	Incidence per 1,000 employees	Age at onset	Duration (years)	Disability Weight	YLDs	YLD per 1,000 employees
Males								
15-29	1,589,507	6	0.0038	22.5	58.5	0.920	152	0.096
30-44	1,699,190	6	0.0035	37.5	43.6	0.920	134	0.079
45-59	465,929	5	0.0107	52.5	29.2	0.920	90	0.192
60-69	36,466	0	0.0000	65.0	18.1	0.920	-	0.000
70-79	3,979	0	0.0000	75.0	10.8	0.920	-	0.000
Total	3,795,072	17	0.0045	36.6	44.6	0.92	376	0.099
Females								
15-29	1,765,593	1	0.0006	22.5	61.1	0.920	25.767	0.015
30-44	1,678,510	2	0.0012	37.5	46.5	0.920	46.122	0.027
45-59	390,871	1	0.0026	52.5	32.2	0.920	19.005	0.049
60-69	19,434	0	0.0000	65.0	20.9	0.920	-	0.000
70-79	2,121	0	0.0000	75.0	12.9	0.920	-	0.000
Total	3,856,528	4	0.0010	37.5	46.6	0.92	91	0.024
Total	**7,651,600**	**21**	**0.0027**				**467**	**0.061**
YLDs per injuries							**22.23**	

Table 6-3. DALY rate injuries for the permanent partial disability in the workplace accident in Thailand in the year 2005.

	Number of Employees	Incidence	Incidence per 1,000 employees	Age at onset	Duration (years)	Disability Weight	YLDs	YLD per 1,000 employees
Males								
15-29	1,589,507	1,205	0.758	22.5	58.5	0.155	5,147	3.24
30-44	1,699,190	1,041	0.612	37.5	43.6	0.155	3,924	2.31
45-59	465,929	276	0.591	52.5	29.2	0.155	832	1.78
60-69	36,466	14	0.387	65.0	18.1	0.155	31	0.84
70-79	3,979	0	0.000	75.0	10.8	0.155	-	0.00
Total	3,795,072	2,535	0.668	32.2	49.0	0.155	9,932	2.62
Females								
15-29	1,765,593	417	0.236	22.5	58.5	0.155	1,782	1.01
30-44	1,678,510	360	0.215	37.5	43.6	0.155	1,359	0.81
45-59	390,871	95	0.244	52.5	29.2	0.155	288	0.74
60-69	19,434	5	0.251	65.0	18.1	0.155	11	0.54
70-79	2,121	0	0.000	75.0	10.8	0.155	-	0.00
Total	3,856,528	878	0.228	32.2	49.0	0.155	3,440	0.89
Total	**7,651,600**	**3,413**	**0.446**				**13,372**	**1.75**
YLDs per injuries							**3.92**	

Table 6-4. DALY rate injuries for the temporary disability more than 3 days caused by the workplace accident in the year 2005.

	Number of Employees	Incidence	Incidence per 1,000 employees	Age at onset	Duration (years)	Disability Weight	YLDs	YLD per 1,000 employees
Males								
15-29	1,589,507	19,832	12.48	22.5	0.0255	0.043	22	0.014
30-44	1,699,190	16,792	9.88	37.5	0.0255	0.043	18	0.011
45-59	465,929	4,654	9.99	52.5	0.0255	0.043	5	0.011
60-69	36,466	232	6.36	65.0	0.0255	0.043	0	0.007
70-79	3,979	0	0.00	75.0	0.0255	0.043	-	0.000
Total	3,795,072	41,510	10.94	32.2	0.0255	0.04	45	0.012
Females								
15-29	1,765,593	4,964	2.81	22.5	0.0255	0.043	5	0.003
30-44	1,678,510	4,204	2.50	37.5	0.0255	0.043	5	0.003
45-59	390,871	1,165	2.98	52.5	0.0255	0.043	1	0.003
60-69	19,434	58	2.99	65.0	0.0255	0.043	0	0.003
70-79	2,121	0	0	75.0	0.0255	0.043	-	0.000
Total	3,856,528	10,391	2.69	32.2	0.0255	0.043	11	0.003
Total	**7,651,600**	**51,901**	**6.78**				**57**	**0.007**
YLDs per injuries							**1.09×10^{-3}**	

Table 6-5. DALY rate injuries for the temporary disability not less than 3 days caused by the workplace accident in the year 2005.

	Number of Employees	Incidence	Incidence per 1,000 employees	Age at onset	Duration (years)	Disability Weight	YLDs	YLD per 1,000 employees
Males								
15-29	1,589,507	62,857	39.55	22.5	0.0073	0.027	13	0.008
30-44	1,699,190	45,263	26.64	37.5	0.0073	0.027	9	0.005
45-59	465,929	9,100	19.53	52.5	0.0073	0.027	2	0.004
60-69	36,466	352	9.64	65.0	0.0073	0.027	0	0.002
70-79	3,979	0	0.00	75.0	0.0073	0.027	-	0.000
Total	3,795,072	117,572	30.98	30.7	0.0073	0.027	23	0.006
Females								
15-29	1,765,593	16,329	9.25	22.5	0.0073	0.027	3	0.002
30-44	1,678,510	11,758	7.01	37.5	0.0073	0.027	2	0.001
45-59	390,871	2,364	6.05	52.5	0.0073	0.027	0	0.001
60-69	19,434	91	4.70	65.0	0.0073	0.027	0	0.001
70-79	2,121	0	0.00	75.0	0.0073	0.027	-	0.000
Total	3,856,528	30,542	7.92	30.7	0.0073	0.027	6	0.002
Total	**7,651,600**	**148,114**	**19.36**				**29**	**0.004**
YLDs per injuries							**1.99×10^{-4}**	

6.4 Application to the Fatal and Non-fatal Occupational Injuries in Thailand

Based on the data of the fatal and non-fatal occupational injuries in the workplace (Chapter 4) and the characterization factor on occupational injuries (Section 6.3), we can estimate the occupational health effects caused by the workplace accidents, as shown in Figure 6-2. The results show that the highest occupational accident intensity is in the saw mill sector (1.45E-02 DALY/million Thai Baht output) follow by metal products (1.41E-02 DALY/million Thai Baht output), construction (1.25E-02 DALY/million Thai Baht output), non-metallic ore and quarrying mining (1.23E-02 DALY/million Thai Baht output), home appliances (1.18E-02 DALY/million Thai Baht output), fertilizers and pesticides (1.14E-02 DALY/million Thai Baht output), wood furniture (1.13E-02 DALY/million Thai Baht output), household machinery (1.01E-02 DALY/million Thai Baht output), business services (9.63E-03 DALY/million Thai Baht output), and iron and steel sector (9.24E-03 DALY/million Thai Baht output). The average DALY per million Thai Baht output injury was 4.64E-03 with the standard deviation of 2.98E-03.

The occupational accident impact intensity in the metal products, iron and steel, household machinery, non-metallic ore and quarrying mining, construction, and fertilizers and pesticides sectors were higher than other sectors due to these being high risk work activities. While, saw mills, wood furniture, home appliances, and business service sectors are high risk work activities and with low economic value. There are more than half of industrial sectors in which the YLLs intensity is larger than the YLDs effect.

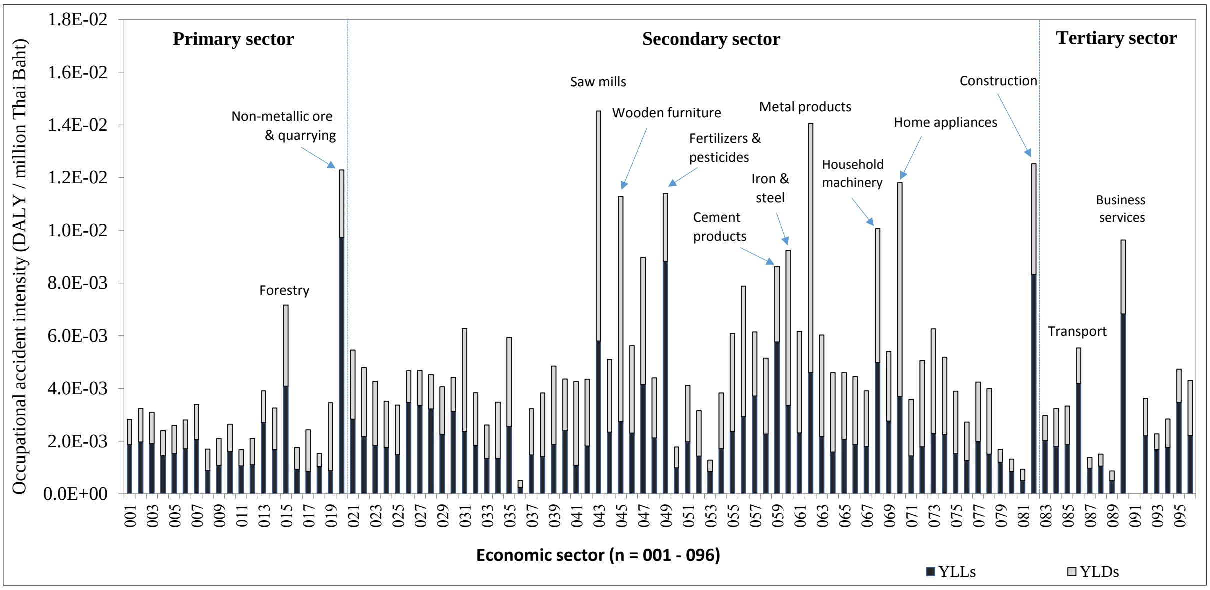

Figure 6-2. Workplace accident intensity in term of DALY for Thai industrial sector using the input-output analysis.

6.5 Conclusions

The aim of this chapter was to develop the characterization factor of the occupational workplace accidents, for a social footprint assessment specifically in Thailand, at the degree of loss level. The five degrees of loss level in Thailand have been calculated using a modified method proposed by WHO (Prüss-Üstün et al., 2003) with consideration for age-weighting and discounting being taken into account in each degree of loss level. In conclusion, the characterization factor developed in this study can be used for the quantification of hotspots and social footprint impact assessments of products in terms of human health impact with social footprint inventory in the chapter 4. The main findings from this study can be summarized as follows:

1) National average DALY rate per 1000 employees in this study was 4.42, which is lower than the result conducted by Simas et al. (2014). Because Simas et al. (2014) analysis included the effect from both disease and accident burdens relevant to workers, whereas this study only considered the workplace accident impacts.

2) High the characterization factor were observed for male workers in all the degrees of loss level due to high risk work activities of male workers.

3) The high characterization factor and occupational health impact developed in this study show which sector the hotspots are, and indicate that potential improvement of health and safety conditions can be achieved by policy tools. In addition, it is possible to find the options for the mitigation of health and safety impacts in the big picture of the industrial sectors.

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Chapter 7. Case Studies - Environmental life cycle assessment and social impacts of bio-based products

7.1 Bioplastic production

7.1.1 Introduction

Nowadays, several million tons of plastics are produced every year. Plastics can be found in everything from clothing to machinery. Plastics are used for packaging materials and almost every type of consumer product, and thus the consumption of plastics continue to rise at an increasing rate. Virtually all plastics are made from petroleum resources, such as oil, coal or natural gas, which will eventually become exhausted and it may take thousands of years for plastics to be biodegraded (Nampoothiri et al., 2010). Renewable materials are materials from natural resources or natural biomass resources such as corn starch, cellulose, cassava and sugarcane (Detzel and Krüger, 2006; NIA, 2008). Bio–based materials are considered an environmental friendly alternative to petroleum–based materials. They can be produced without toxic byproducts and are biodegradable in nature. In addition, the net balance of carbon dioxide of biopolymers is neutral because the CO_2 released during the production and disposal of bioplastics is balanced by the CO_2 consumed during plant growth (Gironi and Piemonte, 2011; Uihlein et al., 2008).

Polylactic acid (PLA) is a sustainable alternative to conventional polymers, because the lactides can be mass produced by the microbial fermentation of agricultural by–products, mainly carbohydrate rich substances (John et al., 2006). Recent developments show that lactic acid can be converted to polylactic acid through two main routes: first, the indirect route via lactide, and second, direct polymerization by polycondensation, producing PLA. Both products are generally referred to as PLA (Wolf, 2005).

This study aims to evaluate the environmental performance associated with PLA production from cassava in Thailand in comparison with PET resin, based on the life cycle approach. The life cycle inventory analysis and impact assessment were carried out based on ISO 14040 for all stages involved in the product systems, which included cassava cultivation and harvesting, starch production, and lactic acid production and PLA resin conversion.

7.1.2 Methodology

The LCA technique used in this study was based on ISO 14040 framework (ISO 2006a) and ISO 14044–guidelines and requirements (ISO 2006b), which consist of four steps; goal and scope definition, inventory analysis, impact assessment, and interpretation.

7.1.2.1. Goal and scope definition

The first step of an LCA is defining the scope and goal of an investigation, which can be established on the analysis and understanding of a product's life cycle, the improvement of production processes, or the use of the results for marketing purposes. The goal of this study was to assess the life cycle environmental and social performance of PLA resin produced from cassava in comparison with PET resin produced in Thailand. The functional unit (FU) of this study was 1 kg resin. The scope of the PLA study includes the cassava cultivation and harvesting, starch production, glucose production, and production of lactic acid, lactides and PLA. The system boundary of the PLA system is shown in Figure 7-1.

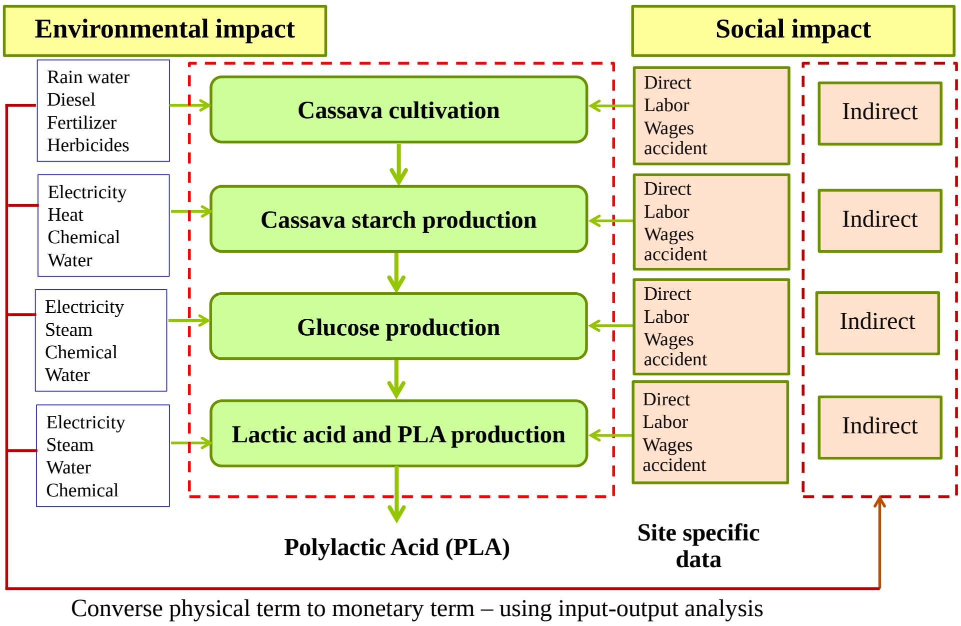


Figure 7-1. System boundary of polylactic acid production.

The biobased polymeric resins were compared on an equal weight basis with petroleum–based resins. The environmental profiles of the petroleum–based polymers were gathered from the national life cycle inventory database of Thailand, which represents an average of production sites in Thailand. The system boundary of the PET system is shown in Figure 7-2.

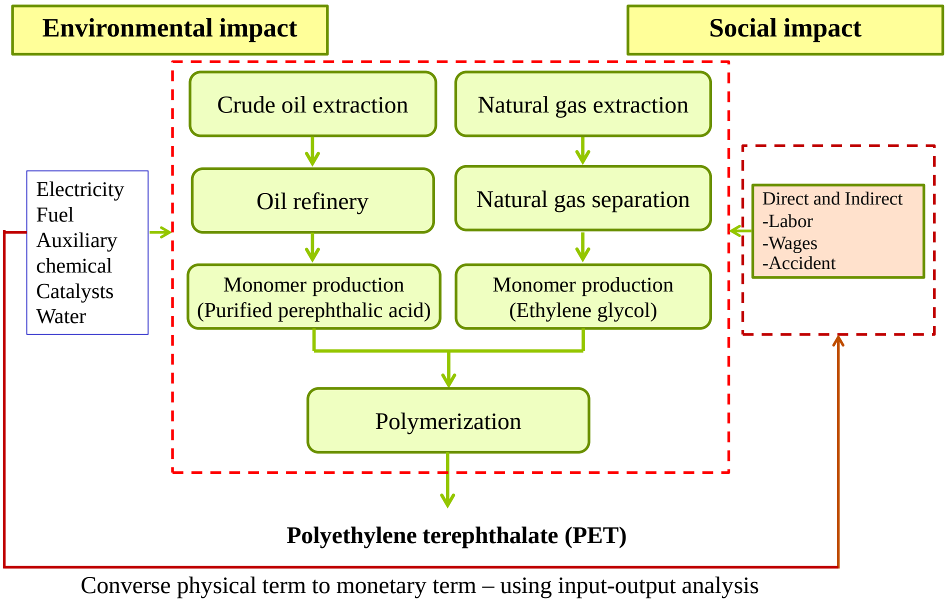


Figure 7-2. System boundary of PET resin production.

7.1.2.2. Data sources, assumptions, and limitations

In this study most of the input–output data were collected as primary data at the actual sites in Thailand, including cassava plantations and harvesting, cassava starch production, and bottle production plants. The collected data included raw materials used, energy consumption, utilities, and waste generated within the system boundary. The secondary data were used in this study as necessary and were obtained from literature, calculations, the Ecoinvent database and the IPCC method for items such as the production of fertilizers, herbicides, etc. However, this study did not take into account CO_2 uptake during the cassava growing for glucose requirements, nor did it include the impacts of infrastructure such as construction of the process plant, equipment maintenance, etc. The background data for this study were gathered from the national life cycle inventory (LCI) databases of Thailand (MTEC, 2011), research reports (MTEC, 2009; DEDE, 2012), and Ecoinvent databases (Ecoinvent, 2008) as described in Table 7-1.

7.1.2.3. Inventory analysis

The inventory data were gathered which include the material and energy inputs, air emissions, waterborne emissions, and solid waste involved in the life cycle of the cassava–based PLA and PET product. All data of the processes were compiled and the inventory analysis was performed based on a functional unit of product. Details of each stage are described in the following sections.

Table 7-1. Sources of background data used in the PLA and PET study.

Background data	Source
Fertilizers production	Ecoinvent (2008)
Herbicides production	Ecoinvent (2008)
Crude oil production	Ecoinvent (2008)
Chemicals production	Ecoinvent (2008)
Terephthalic acid production	Adjusted from Ecoinvent (2008)[1]
Ethylene glycol production	Adjusted from Ecoinvent (2008)[1]
PET resin production	Adjusted from Ecoinvent (2008)[2]
Road transport by truck	MTEC (2011)
Diesel production	MTEC (2011)
Natural gas production	MTEC (2011)
Electricity grid–mixed production	MTEC (2009) and DEDE (2012)
Steam production	Adjusted from Ecoinvent (2008)[3]
Combined heat and power (CHP) system	Adjusted from Ecoinvent (2008)[3]

Remarks: [1] adjusted by replacement with the data from Thai electricity and heat databases.

[2] adjusted by replacement with Thai database such as energy sources and feedstock ratio.

[3] adjusted by replacement with Thai database such as natural gas and electricity.

7.1.2.3.1 Cassava cultivation and harvesting stage

The main concentration of the cassava planting is now found in the northeast of Thailand, especially in Nakhonratchasima province. Cassava has excellent drought tolerance properties and can be planted in almost all soil types. It is mostly grown by a large number of farmers, who own small plots of land. Few organized large–scale plantations have been established in Thailand, as this is prohibited by the land reform act. The cassava harvested area, for the whole country, in 2011 was 1.14 million hectares and production yield was 19.30 tonne of fresh roots per hectare (OAE, 2012). The cassava farming activities include land preparation, planting, fertilization, weeding, and harvesting. The foreground data on fuel, lubrication oil, fertilizers, and herbicides inputs were collected through a field survey in 2011, in Nakhonratchasima and Chaiyaphum provinces, the northeastern cultivating areas of the country. With respect to the allocation method for this stage, since cassava stems are mainly used for new planting which is considered as an internal use in the system, the environmental loads of the cassava cultivation and harvesting stage are allocated only to the cassava roots. The carbon dioxide from the air and solar energy for the photosynthesis process were excluded in this analysis. Emissions to air during preparation of cassava fields of planting and emissions from fertilizers during growth are included. For emissions during cassava growing from nitrogen fertilizer, it was assumed that of the total N applied 10% will be evaporated as NH_3, and 1% is assumed to be evaporated as N_2O–N (IPCC, 2006). Some relevant data on this stage and activities used in the analysis are shown in Table 7-2.

Table 7-2. Inventory data of cassava root cultivation stage.

Flow	Unit	Amount	Type	Related activities
Inputs				
Fertilizers (N–P–K): 15 –15–15	kg/ha/year	154±15	Material input	Fertilizer application
Fertilizers (N–P–K): 16 –8–8	kg/ha/year	33±5	Material input	Fertilizer application
Fertilizers (N–P–K): 46 –0–0	kg/ha/year	48±4	Material input	Fertilizer application
Paraquat	kg active ingredient/ha/year	0.96±0.27	Material input	Weeding
Glyphosate	kg active ingredient/ha/year	1.44±0.52	Material input	Weeding
Diesel	l/ha/year	35±12	Energy input	Soil preparation, weeding, and harvesting
Outputs				
Cassava roots	tonne fresh roots/ha/year	19.30	Product output	
Cassava stems	tonne/ha/year	3.6	Internal flow	Use in new planting

7.1.2.3.2 Cassava starch production stage

One kilogram of cassava starch requires 3.9–4.5 kilograms of fresh cassava roots at its starch content is only 25% (Chavalparit and Ongwandee, 2009). In Thailand, the large–scale processing facilities with advanced processing machines and technology have been replacing the primitive and small–scale factories. The cassava starch processing methods could be divided into two processes; traditional and modern. The modern process, typically practices in the large–and–medium–scale factories, relies on a number of pieces of highly efficient equipment and machines. The production process may be divided into eight steps as follows: determining the starch percentage; removing sand and impurities in the rotary screener; peeling, cleansing and chopping out root rails; putting the fresh clean cassava into the Rasper and then Decanter to remove the protein; passing the slurry through a screen to remove the fibers; separating the fine fibers and impurities using a centrifuge; drying out the starch by passing it through the hot–aired dryer column; and finally packing the fine powder into sacks for sale. Inventory data were gathered from three cassava starch factories in Nakhonratchasima and Chachoengsoa provinces and are summarized in Table 7-3. The environmental burdens of the cassava starch production system are allocated between the cassava starch and cassava pulp, based on a mass allocation approach in term of starch content. In the base case scenario based on the current situation of Thai cassava starch industry, this is assumed to require heat generated from fuel oil (45%) and biogas (55%) (NSTDA, 2011), and electricity from the national grid. The improvement option (option I) is the complete replacement of fuel oil by biogas from anaerobic treatment of the mill effluents.

Table 7-3. Inventory data of cassava starch production stage.

Flow	Unit	Amount		Type	Related activities
		Base case	Option I		
Inputs					
Cassava root	kg/kg starch	4.33±0.39	4.33±0.39	Material input	Farming
Water	l/kg starch	18.65±7.16	18.65±7.16	Material input	Processing water and steam production
Fuel oil	MJ/kg starch	1.28±0.67	0	Energy input	Burning for steam and electricity production
Biogas	m^3/kg starch	0.03±0.03	0.06±0.01	Internal flow	Burning for steam and electricity production
Electricity	kg/kg starch	0.21±0.04	0.18±0.01	Energy input	In process electricity use
Outputs					
Cassava starch (13% MC)	kg/kg starch	1.00	1.00	Product output	Allocation by starch content
Cassava pulp (dry mass)	kg/kg starch	0.39	0.39	By-product	Allocation by starch content

7.1.2.3.3 Glucose production stage

Commercially, glucose is produced via the enzymatic hydrolysis starch for which many crops can be used as the source of starch such as corn, wheat, cassava, rice, etc. Glucose production from cassava starch consists of three steps: liquefaction, saccharification, and purification. Because information on energy used in glucose production from cassava in Thailand has not been published, this study has gathered the inventory data from the report on the financial and economic viability of bioplastics production in Thailand (Chiarakorn et al., 2011), and Renouf et al. (2008). One kilogram of glucose production requires 0.144 kWh of electricity and 0.0067 liters of fuel oil.

7.1.2.3.4 Lactic acid, lactide and PLA production stage

Glucose is converted to lactic acid by fermentation, followed by purification. The fermentation process requires energy use (steam and electricity) and contributes substantially to the fossil energy demand of PLA. Sulfuric acid, calcium carbonate, and auxiliary chemicals are required as operating supplies. The PLA manufacturing from lactic acid occurs in two steps. The first step is the conversion of lactic acid into the lactide, and then purification by distillation. In the second step the polymerization of lactide to polylactide takes place in the presence of a tin catalyst. Inventory data on the energy use and process chemical demand for the lactic acid, lactide, and polylactide production were extracted from Groot and Borén (2010). Based on one kilogram of PLA, the production requires 0.97 kWh of electricity and 12.74 MJ of steam. This study considered two different scenarios as described below:

- Base case – electricity from national grid and steam production from natural gas were used to assess the environmental performance of the product systems.
- Option II – electricity and steam production from natural gas based on combined heat and power (CHP) system was used to evaluate the impact on environment of the product systems.

7.1.2.3.5 PET resin production

The inventory data of PET resin production are divided into five major stages including raw material extraction, primary material production, monomer production, PET production, and related transport. The raw material extraction stage involves crude oil extraction and natural gas extraction, background data being gathered from Ecoinvent database (Ecoinvent, 2008). Transport of crude oil from the Middle East and South of Asia to the oil refineries at Rayong province, in the east of the country, by ocean tanker was estimated at 6,700 km, whereas natural gas is piped transmission from the Gulf of Thailand to the Rayong gas separation plants. At the oil refinery, crude oil is processed to produce naphtha and then cracked to paraxylene. At the gas separation, natural gas is processed to produce ethane which is a feedstock to produce olefins. Inventory data of oil refinery and natural gas separation were gathered from the national LCI database of Thailand (MTEC, 2011). The monomer production stage includes the production of purified terephthalic acid (PTA) and monoethylene glycol (MEG). PTA is produced via oxidation reaction of paraxylene with acetic acid as solvent and cobalt as a catalyst. The production of one kg of PTA requires 0.66 kg of paraxylene, 0.43 kg of water, 0.47 kWh of electricity and 3.93 MJ of heat (Ecoinvent, 2008). MEG is produced from ethylene via intermediate derivative of ethylene oxide by reaction with water then conversion to MEG. The production of one kg of MEG requires 0.72 kg of ethylene oxide, 6.18 kg of water, and 0.39 kWh of electricity, whereas one kg of ethylene oxide is produced from 0.83 kg of ethylene, 0.46 kg of liquid oxygen, and 0.33 kWh of electricity (Ecoinvent, 2008). The inventory data of both monomers were adjusted from the Ecoinvent database using the electricity and heat data from Thai databases developed by MTEC (2009). PET resin is produced by reacting PTA with MEG and catalyst. The main production process steps are raw material preparation, esterification, pre-polycondensation, and polycondensation. Based on one kg of PET resin, the production requires 0.87 kg of PTA, 0.35 kg of MEG (Indorama Venture Public Company Limited, 2012), 0.38 kWh of electricity, and 6.3 MJ of heat (Ecoinvent, 2008). Inventory data of PET production in this study were adjusted data from the Ecoinvent database by replacement with Thai database such as energy sources and feedstock ratio.

7.1.2.4 Social impact analysis

The social indicators selected in this study are the employment generation, wages, and fatal occupational health and safety. In this study, we use the hybrid approach by combining the process-based approach (site specific data) and top-down approach (input-output analysis), to evaluate the employment, wages, and fatal occupational injury impacts of bioplastic production, in Thailand.

7.1.2.4.1 Direct employment, wages, and fatal occupational injury in the agricultural stage

For the direct employment, wages, and occupational injury effects on the agriculture stage in this study, we collected data about the number of employees, wage rates, and accidents in farming in combination with the cultivation area and production yields from the 300 farmers in top five provinces, which are highest planting area. In addition, the secondary data from the literature used to fulfil in the analysis. The expenditures relating to labor costs for land preparation, planting, fertilizing, weeding, and harvesting are gathered from interviews and previous studies. To determine the amount of direct employment in cultivation and harvesting the labor costs data in farming can be divided by the average worked hours in agricultural sector.

7.1.2.4.2 Direct employment, wages, and fatal occupational injury in the industrial stages

To determine the direct employment, wages, and occupational accidents in the workplaces of the industrial stages (feedstock processing and bioethanol production), we collected the data on the number of workers, wage rate, the number of fatal occupational injuries, and the production capacities from 3 cassava starch factories, 2 glucose factories, and literature reviews of the bioplastic production.

7.1.2.4.3 Indirect employment and occupational injury analysis

This study used the input–output analysis to evaluate the social footprints embodied in the bioethanol system. We used the 2005 Thailand IO table for evaluating the social impact that consists in 180 economic sectors, aggregated to 96 sectors based on the social intensity data from Papong et al. (2015). The socio-economic impacts that are directly and indirectly induced by bioethanol production system can be estimated using Equations (7-1) to (7-2).

$$X = (I - A)^{-1} F \qquad (7\text{-}1)$$

where $(I–A)^{-1}$ is the Leontief inverse matrix that represents the total effect both direct and indirect inputs to fulfill one unit of final consumption in monetary value; I is the identity matrix.

Let S as the total social input required to satisfy the final consumption. We can extend the IO relationship derived equation (8) as follow:

$$S = s\,X = s\,(I - A)^{-1} F \qquad (7\text{-}2)$$

where *S* is the direct and indirect social vector, *s* is the diagonal matrix of social impact coefficient.

The statistical data on the fatal occupational injuries in Thailand were obtained from Thailand's Social Security Office (SSO, 2006). Only 23.23% of all occupational accidents in Thailand are covered in the SSO databases. The total fatal accidents in Thailand were adjusted using the ratio of (100%/23.23% = 4.30).

7.1.3 Results and discussions

7.1.3.1 Global warming potential (GWP)

In this section, the life cycle impact assessment (LCIA) was analyzed for 1 kg of PLA and PET resin for the relevant impact categories using the impact assessment model based on the CML 2 baseline 2000. As PLA resin is currently produced in Thailand by Purac (Thailand) so the production of PLA resin based on Purac (Thailand) was used as a base model for this study, with a modification that cassava was used instead of sugar. In this part, we focused on GWP represented by GHG emissions (kg CO_2 eq.) as shown in Figure 7-3. For PLA resin production life cycle, the total GHG emission for cassava–based PLA resin production was based on the base case scenario which was 2.48 kg CO_2 eq. per kg resin. In this scenario, the major GHG emissions (about 57.30%) came from the polymerization process due to energy consumption, including steam and grid electricity. The second part of the GHG emissions came from cassava starch production, accounting for 28.42%, due to CH_4 emissions from the wastewater treatment process. In the cultivation stage, GHG emissions accounting for 6.94%, mainly came from fertilizer utilization and N_2O emission from N-fertilizers. Consequently, the full utilization of biogas from the wastewater treatment of cassava starch production has been proposed as an improvement option (option I) to help reduce GWP. The net GHG for this option was found to reduce to 1.96 kg CO_2 eq. per kg resin. Based on option I, the PLA production stage could be further improved to option II by additional installation of a combined heat and power (CHP) system instead of the grid electricity and steam energy from natural gas. For this option, net GHG could be reduced to 1.54 kg CO_2 eq. per kg resin.

Concerning GWP of plastic resin, several studies (Detzel and Krüger, 2006; Vink et al., 2007; Groot and Borén, 2010; Gironi and Piemonte, 2011) have shown that PLA resin had lower GWP than its fossil–based resins such as PET, PS and PP which is in good agreement with our study. When comparing our results with a similar study by Groot and Borén, 2010, they reported GHG emissions of 0.50–0.80 kg CO_2 eq. per kg sugarcane–based PLA produced in Thailand. This is lower than the value obtained in our study, which was 1.54–2.48 kg CO_2 eq. per kg cassava–based PLA. The main difference was that Groot and Borén (2010) study also took into account CO_2 uptake during sugarcane cultivation, while CO_2 uptake during cassava cultivation was not included in our study because we considered that CO_2 was released into the atmosphere at the end–of–life of the PLA product, thus net CO_2 balance was zero. When compared to the corn–based PLA studied by Vink et al. (2010) and Gironi and Piemonte (2011), they reported the GHG emissions of 1.30 and 1.09 kg CO_2 eq. per kg corn–based PLA, respectively, which were lower than the value obtained in our study for cassava–based PLA. The same reason as above could be used to explain this difference since they also took into account the CO_2 uptake during corn growing.

Based on the functional unit defined in this study (1 kg resin) it was found that the total GHG emissions of cassava–based PLA resin was lower than that of PET resin as shown in Figure 7-3.

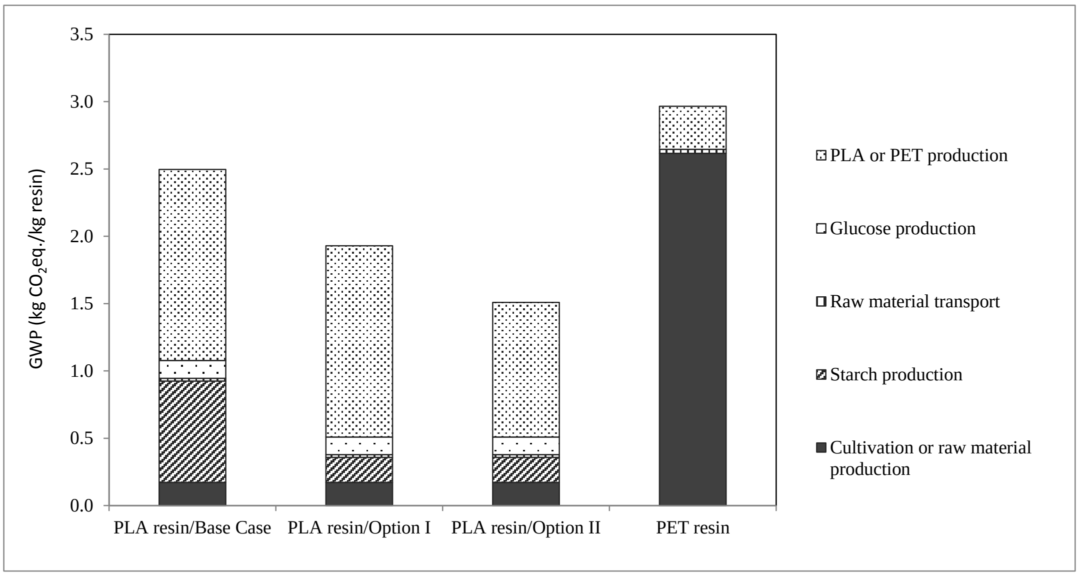


Figure 7-3. Comparison the GHG emissions of PLA resin and PET resin.

7.1.3.2 Acidification potential

The second impact category considered in this study was acidification potential (AP). The AP of cassava–based PLA resin production for the base case scenario, option I, and option II was 16.16, 15.91, and 14.51 g SO_2 eq. per kg resin, respectively. When comparing the results of this study with Groot and Borén (2010), our study showed lower AP than that of the sugarcane–based PLA. This is mainly due to the greater amounts of SO_2 and NOx generated in the sugar production from sugarcane as compared to cassava starch production, and SO_2 emissions from sulfuric acid production that is used in the lactic acid production process. However, in comparison with the study of Gironi and Piemonte (2011), they reported the AP impact of 11.52 g SO_2 eq. per kg corn–based PLA which was lower than the value obtained in our study for cassava–based PLA. The main reason is due to the difference of sources of electricity used in the PLA production process. Figure 7-4 shows the comparison of AP of the three PLA cases and PET resin for the functional unit of 1 kg resin. The results revealed that cassava–based PLA resin cases have higher AP than PET resin.

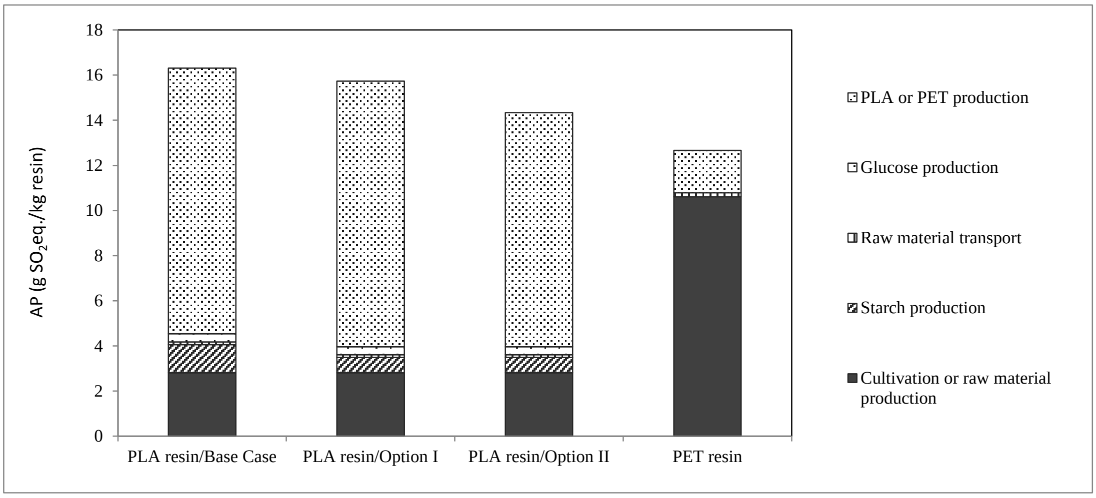


Figure 7-4. Comparison the AP impact of PLA resin and PET resin.

7.1.3.3 Eutrophication potential

The eutrophication potential (EP) of PLA resin for the base case scenario, option I, and option II was shown to be 9.22, 3.74, and 3.53 g PO_4 eq. per kg resin, respectively. In the base case scenario, the results showed that EP impact mainly comes from cassava starch production stage accounting for 71.04%, and secondly from the cassava cultivation stage accounting for 20.73%. While in option I and II, the EP impact mainly comes from cultivation, starch production, and PLA production stage, respectively. When compared the results of this study with Groot and Borén (2010) and Gironi and Piemonte (2011), two cases of this study (option I and option II) have lower EP than that of the sugarcane and corn–based PLA whereas the base case of this study has higher EP than the sugarcane and corn–based PLA. This is mainly due to higher chemical oxygen demand (COD) generated in the cassava starch production as compared to sugar production from sugarcane and dextrose production from corn. For the comparison at the production stage as shown in Figure 7-5, the results revealed that PLA resin had higher impact than PET resin, especially in the base case scenario. Low EP impact of PET resin is mainly due to low chemical oxygen demand (COD) in wastewater in the PET resin production which is a petrochemical catalysis process.

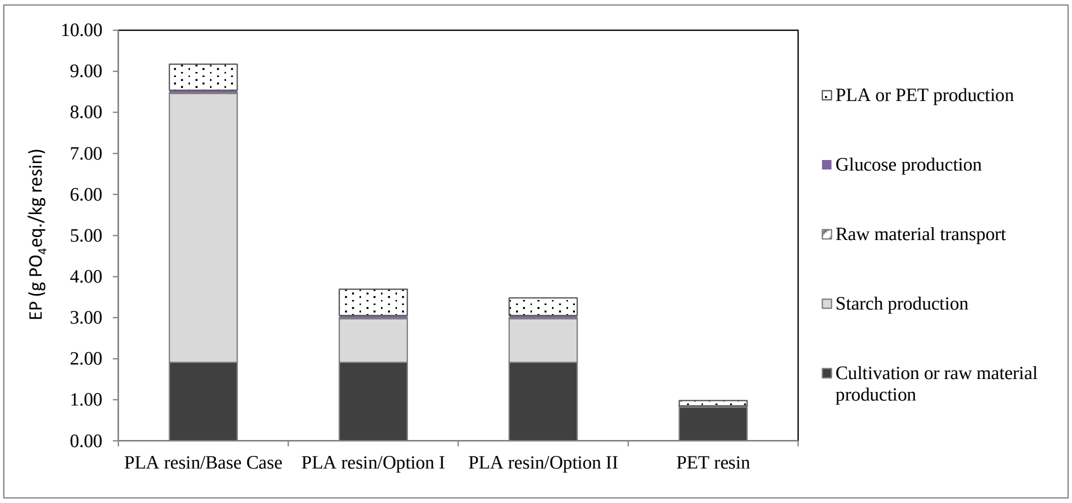


Figure 7-5. Comparison the EP impact of PLA resin and PET resin.

7.1.3.4 Human toxicity potential

The human toxicity potential (HTP) of PLA resin for the base case scenario, option I, and option II was shown to be 2.67, 2.52, and 1.34 kg 1,4-DB eq. per kg resin, respectively. In comparison with Groot and Borén (2010), the results of our study have lower HTP than that of the sugarcane–based PLA. This is mainly due to greater amount of harmful emissions (such as NOx, SO_2, particulates) generated from bagasse combustion in the sugar production from sugarcane as compared to cassava starch production. From the comparison at the production stage shown in Figure 7-6, the results showed that PLA resin had lower impact than PET resin. High HTP impact of PET resin is mainly due to the greater amount of harmful emissions from terephthalic acid and ethylene glycol production processes.

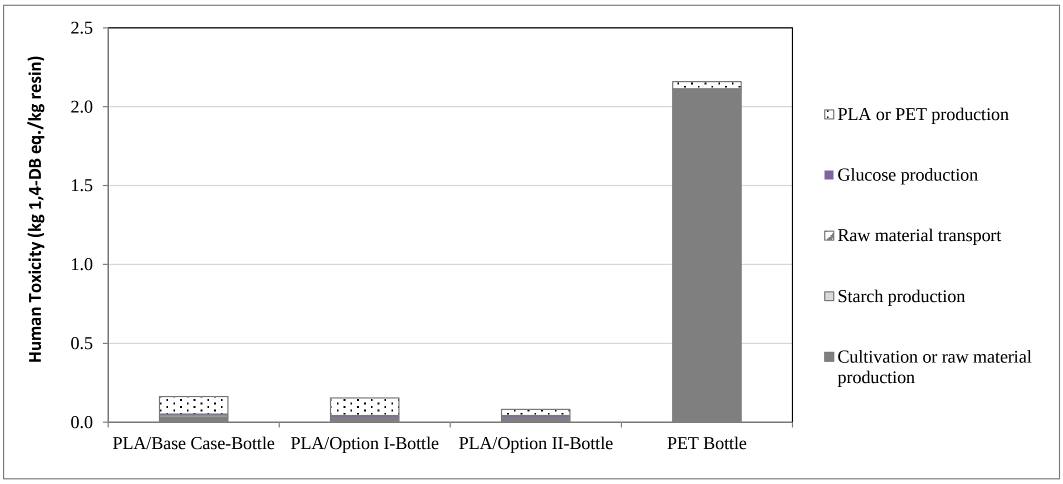


Figure 7-6. Comparison the HTP impact of PLA resin and PET resin.

7.1.3.5 Socio-economic impact

7.1.3.5.1 Impact on employment

Figure 7-7 showed the total employments generated by bioplastic production in Thailand in comparison with PET resin. The results showed that the PLA production system generated total employment of 0.25 persons per tonne PLA. The employment in the feedstock production (from cassava cultivation to glucose production) provides the most employment benefits contributing more than 83% of the total employment generated in the PLA system. The high employment in agriculture indicates that the bioplastic promotion policy actually helps the rural area development in Thailand. In addition, in the developing countries such as Thailand, the agriculture sector is a higher labor intensity due to the cultivating systems are normally performed on the small scale farming and almost manual operation practices.

Based on the total employment aspects, PLA production requires about 8.6 times more workers than PET resin.

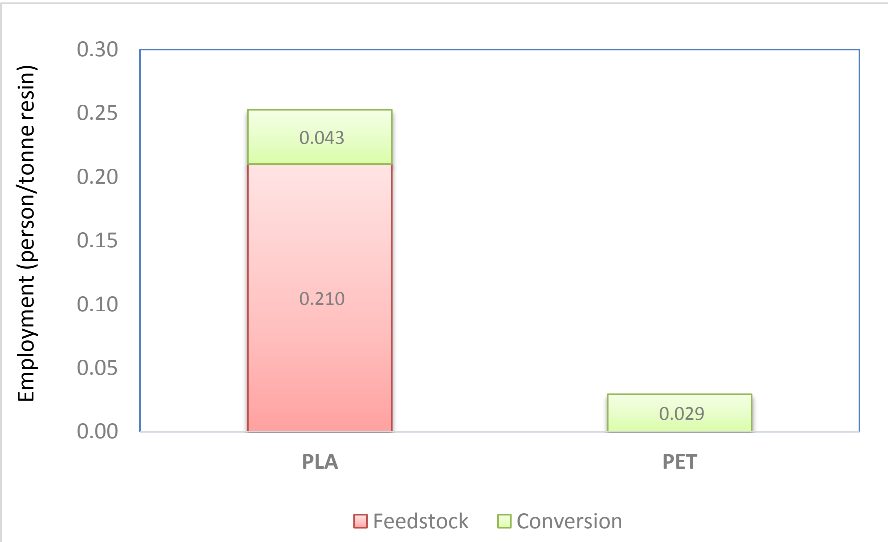


Figure 7-7. Comparison the total employment of PLA and PET resin.

7.1.3.5.2 Impact on wages

The wage impacts demonstrate how much wages would increase in the industrial sectors due to the bioplastic policy implementation. The direct and indirect wage impacts of bioplastic production in Thailand is presented in Figure 7-8. The overall impacts of the PLA production is 289 US$ per tonne PLA. The wage impacts produced by PLA are the highest in the conversion stage, approximately 54% of the total wage impacts. The higher wage impacts are the indirect compensation of employees in the chemical used in the PLA factory. When comparing the wage paid to employees, the whole PLA supply chain has higher wages than PET resin. This aspect is due to the wage rate in the chemical production sector that import from other countries.

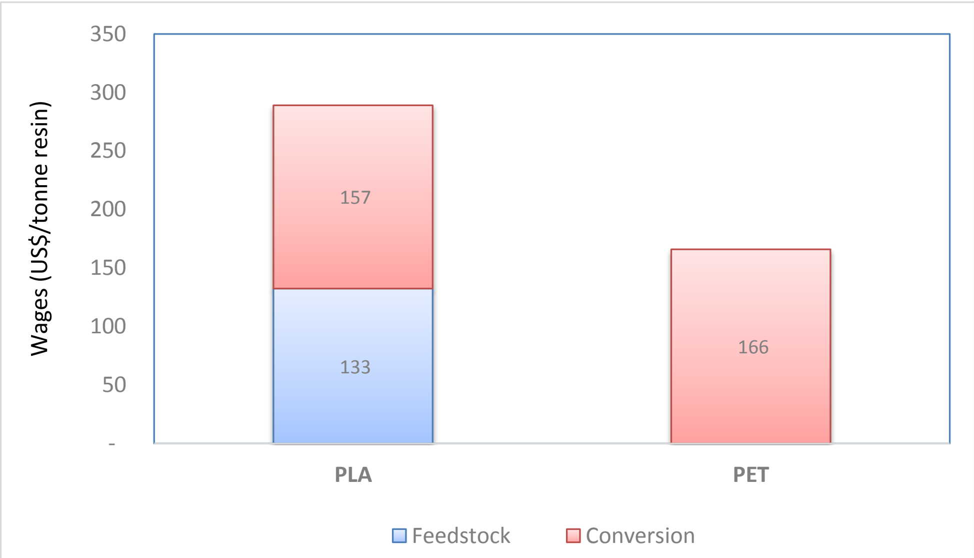


Figure 7-8. Comparison the wages paid to employees of PLA and PET resin.

7.1.3.5.3 Impact on fatal occupational injuries

The total fatal occupational health and safety caused by PLA production in Thailand are estimated as shown in Figure 7-9. Based on the primary data from on-site survey in the period 2014, the cassava cultivation stage, and the cassava starch factories in Thailand had not encountered a direct fatal accident in the workplace. There are no the fatal accident in the agriculture sector due to the farming operation systems in Thailand as they are generally carried out by the small scale farmers in less mechanized operations. According to an interview with the plant safety managers and employees in cassava starch factories, there're no recorded fatal accident cases in any of the factories.

When comparing the embodied fatal occupational injuries between PLA and PET, the result showed that the PLA supply chain has higher risk than that of PET. Due to the security system and safety standard in the petrochemical industry sector are very higher than other sector.

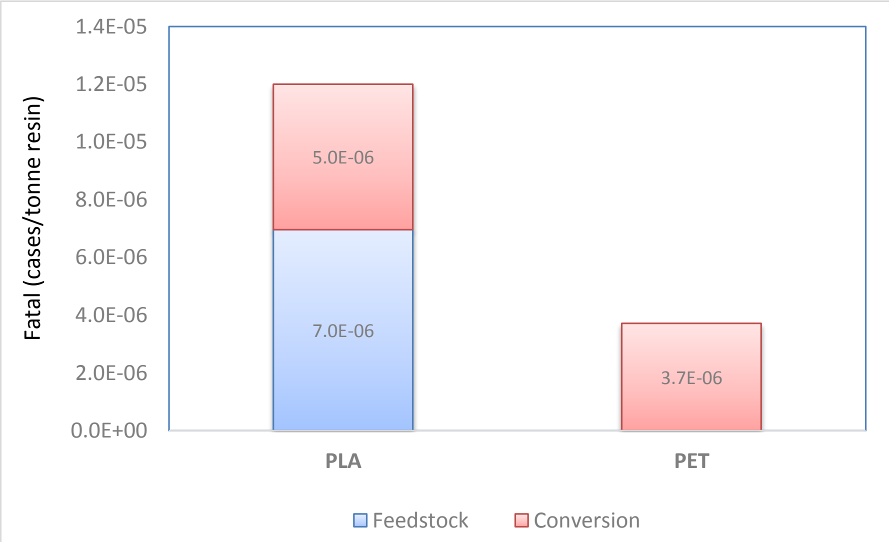


Figure 7-9. Comparison the fatal accident in the workplace of PLA and PET resin.

7.1.4 Conclusions

This study evaluated the environmental performance of PLA and PET resin based on a life cycle perspective. For cradle–to–gate analysis, PET resin contributed higher values in the GWP and HTP, whereas PLA resin was higher in the EP and AP. It is shown that PLA resin can reduce CO_2 emissions and human toxicity. On the other hand, PLA causes high impact in terms of eutrophication due to a high COD in cassava starch wastewater generated for the base case scenario. Based on option I and option II, EP impact of PLA was highest due to the cultivation stage because cassava planting requires the use of agrochemicals such as fertilizers and pesticides that contributed to eutrophication potential. The results showed that cassava–based PLA resin had a much higher GHG emissions than sugarcane–based and corn–based PLA. This can be explained that both the sugarcane and corn–based PLA took into account the CO_2 uptake during the plant growth, while CO_2 uptake during the cassava cultivation of the cassava–based PLA was not included since CO_2 uptake was released into the atmosphere at the end–of–life of the PLA product. However, the overall GWP can be lowered by improvement options proposed in this study which are improved utilization of wastewater from cassava starch plant to produce biogas for steam and electricity production, and applying a CHP system in the PLA plant. By incorporating these improvement options in the analysis, the GWP performance of cassava–based PLA has shown to be better than conventional plastics, such as PET, which are used to produce to the same products.

For the social aspects, the result of this study showed that the bioplastic promotion has a significant impact on the social and economic development in Thailand especially in the agricultural sector in rural area. This result indicated that PLA production from cassava in Thailand have the positive impact in terms of employment generation and incomes. The total employment along the supply chain of bioethanol is about 8.6 times higher than conventional plastic (PET). The total employment in the feedstock stage (from the cultivation to glucose production) created 83% more employment throughout the overall supply chain. For the wage impacts, the result showed that the PLA production could increase the income distribution in agriculture workers in the rural area of the country. In addition, in term of the fatal occupational injury aspects, the result presented that PLA system has a higher impact than PET. It should be improved by promoting and encourage the training and disseminating on the safety and health impacts in the workplace whole the supply chain.

7.2 Bioethanol Production

7.2.1 Introduction

Since the energy crisis, energy demand has continued to rise and even the fossil energy sources and new energy generation from other sources is not enough to meet demand. These causes lead to impacts on the volatility of energy prices on the world market. Thailand relies on energy imports from abroad leading to a loss of foreign currency and the government being required to subsidise the domestic oil price to maintain the oil price is too high. In addition, the use of fossil fuels has an impact on the environment, especially greenhouse gas emitted into the atmosphere, which leads to the greenhouse effect. As a result, the temperature rise is a major problem that is affecting all regions of the world. Most countries, with a focus on research and development of renewable and alternative fuels to reduce fossil fuel consumption are gone. Result from renewable energy interests, particularly biofuels drive the increasing biofuels demand of the world. Currently, the rapid growth of industrial production, biofuels from food crops are starting to cause concerns regarding adverse effects on both the environmental and social happenings, such as food and energy competition. In addition, the occurrence of increasing greenhouse gas emissions from carbon stock loss due to changes in the land use, loss of biodiversity, impact of holding the land by small farmers, impact on employment and child labour are beginning to develop into the international standard on sustainable biofuels. The Global Bioenergy Partnership Sustainability Indicators for

Bioenergy (GBEP, 2011), the Roundtable on Sustainable Biomaterials (RSB, 2009), Renewable Energy Directive of the European Union (EU, 2009), and the Renewable Fuel Standard (RFS) of the United States (EPA, 2007), etc., had been set up for promoting the sustainable biofuels production and consumption.

At present, the Thai government has promoted the production and use of renewable energy, this is designated as part of a national agenda to reduce imports of crude oil from overseas and to mitigate global warming problems. An obvious example is the alternative energy development plan in 2015 (AEDP2015) targets a proportional increase in renewable energy to 30% of final energy consumption of the country, by 2036 (DEDE, 2015). Bioethanol from cassava and sugarcane are the industry targets that play a critical role in the country's production of renewable energy in the present. Its current production of ethanol from cassava and sugarcane molasses are approximately 0.87 and 2.65 million liters per day, respectively (DEDE, 2015). At the end of January 2016, Thailand had 21 factories operating to produce bioethanol with a total capacity of 4.44 million liters (ML)/day or 1332 ML per year based on 300 working days. Sugarcane molasses and cassava are two feedstocks for this industrial purpose. There are 17 factories using only a single feedstock; 9 factories using molasses with a total production capacity of 1.93 ML/day, 7 factories using cassava with a total production capacity of 1.430 ML/day and only 1 factory using sugarcane juice with the production capacity of 0.23 ML/day. A multi-feedstock process using both molasses and cassava is present in 4 factories with a total production capacity of 0.85 ML/day) to avoid feedstock shortages and high-priced feedstock. In addition, there are 2 factories currently under plant construction (DEDE, 2016).

An Environmental Life Cycle Assessment (E-LCA) is a helpful tool for evaluating and quantifying the environmental consequences relevant to a product, process, or service from the cradle to the grave, using a systematic approach (ISO, 2006). In addition, the social dimensions can be included in the LCA method to evaluate the social impact of the product, the so-called social LCA (S-LCA). The result of the E-LCA and S-LCA is communicating information to stakeholders on the environmental and social performance. When considering environmental sustainability as a principle, there are several studies that evaluated greenhouse gas (GHG) and other environmental aspects of bioethanol in Thailand, using the LCA method (Gheewala, 2008; Silalertruksa and Gheewala, 2009; Papong and Malakul, 2010; Moriizumi et al., 2012; Numjuncharoen et al., 2015; Kawasaki et al., 2015; Silalertruksa, et al. (2015). There are also

LCA studies of bioethanol in China (Leng, 2008; Zhang et al., 2012; Liu et al., 2013), Brazil (Pereira and Ortega, 2010; Cavalett et al., 2012; Khatiwada et al., 2012; Duarte et al., 2013; Gnansounou et al., 2015) and Vietnam (Le et al., 2013). There are some case studies focused on the effect of land use change on GHG emissions of bioethanol production (Siralertruksa et al., 2009; Walter et al., 2011; Egeskog, et al., 2014). In addition, the socio-economic impacts in term of employment generation, income, and value added of bioethanol production were addressed in some previous studies (Silalertruksa and Gheewala, 2011; Martinez et al., 2013; Walter et al., 2011).

Although previous studies in Thailand have evaluated the environmental and socio-economic impacts of bioethanol from cassava and molasses; the studies were mainly based on the site-specific data of some factories, which has not yet covered a wide variety of current production systems. In addition, the socio-economic sustainability issues still lack clear information. Therefore, this study is intended to assess the environmental and social sustainability of bioethanol from cassava and molasses in Thailand, based on the life cycle approach.

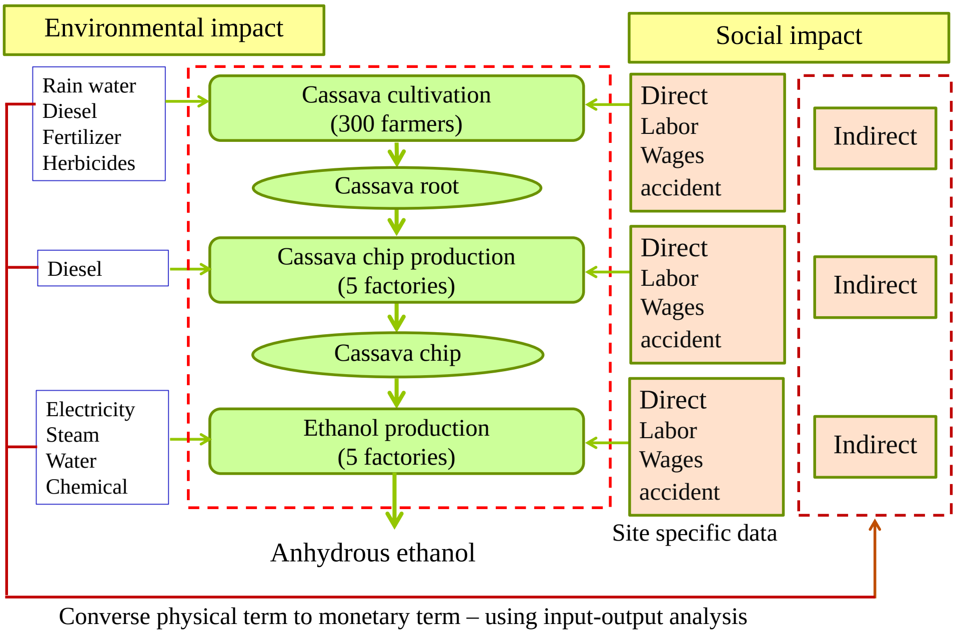
7.2.2 Methodology

7.2.2.1 Goal and scope of the study

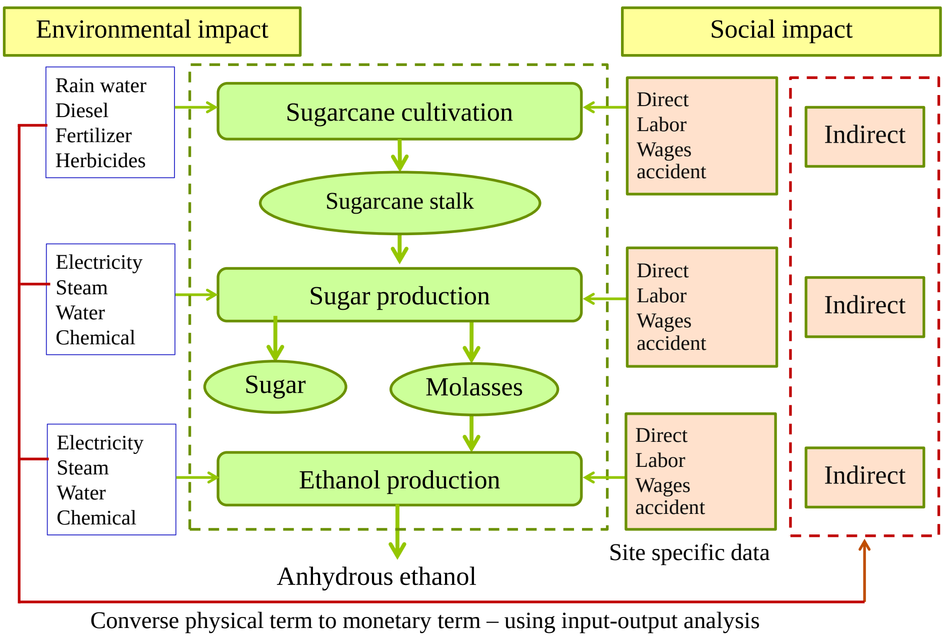
This study aims to evaluate the environmental and social impacts of bioethanol production from cassava and molasses in Thailand via the life cycle perspective. The analysis focused on (1) the identification of key environmental and social issues of bioethanol production from both feedstocks in comparison with conventional gasoline, and (2) suggestions to improve the environmental and social performance of ethanol production in Thailand.

The scope of the study is from cradle to gate including the feedstock cultivation and harvesting, feedstock processing, ethanol production, and related transport. The system boundary is presented in Figure 7-10. The functional unit of the study is 1 GJ of ethanol produced.

The life cycle impact assessment method in this study was selected the ReCiPe method by using the SimaPro 8.0 software. The environmental impact categories considered in this analysis are climate change or greenhouse gas (GHG) emissions, acidification potential (AP), eutrophication potential (EP), and human toxicity potential (HTP). In addition, the GHG emissions from the direct land use change (dLUC) was considered in this study. The water impact potential was selected, along with the water stress index of Thailand, to assess this aspect. These environmental impact categories considered in this analysis are interrelated in the Thailand perspective. The social impacts were considered in this study, including the total employment, wages, and fatal occupational injuries.



(a) Cassava-based ethanol



(b) Molasses-based ethanol

Figure 7-10. System boundary of bioethanol production from cassava and molasses.

7.2.2.2 Data sources

The input-output data in this study mostly were gathered from the primary sources at the actual sites in Thailand. The data included the consumption of raw materials, energy, water, chemicals, and waste generation in the whole supply chain. The secondary data were obtained from the literature, the Ecoinvent database, and calculation based on the IPCC guidelines and the EEA guidebook. However, this study excluded the CO_2 uptake during the crop growing stage, and did not include the environmental impacts from infrastructure facilities such as construction of the factory, machinery manufacturing, etc. The background data for the analysis were obtained from the national life cycle inventory (LCI) databases of Thailand (MTEC, 2011), previously studied, and the Ecoinvent databases as presented in Table 7-4.

Table 7-4. Sources of background data used in the bioethanol study.

Background data	Source
Fertilizers production	Ecoinvent (2012)
Herbicides production	Ecoinvent (2012)
Chemicals production	Ecoinvent (2012)
Road transport by truck	MTEC (2011)
Diesel and gasoline production	MTEC (2011)
Natural gas production	MTEC (2011)
Electricity grid–mixed production [1]	Ecoinvent (2012) and DEDE (2014)

Remarks: [1] adjusted the ratio of Thai electricity in the ecoinvent version 3 based on national statistical from DEDE (2014).

7.2.2.3 Inventory analysis

7.2.2.3.1 Cassava-based ethanol

The system boundaries of ethanol production from cassava includes the cultivation and harvesting of cassava, transportation of the cassava root to the cassava chip production facility, production of cassava chips, transport of the cassava chips to the ethanol factory, and the ethanol production. The details of each stage are explained as follows.

7.2.2.3.1.1 Cassava cultivation and harvesting

In 2015, the cassava harvesting area was a total of 1.37 million hectares, producing approximately 30 million tons of fresh cassava root. The average yield was estimated at 22 tons per hectares. The harvesting areas in the north-eastern were the greatest with 52% of the country's yield followed by the central (26%) and the northern (22%) regions (OAE, 2015).

The cultivation steps include land preparation, planting, fertilizing, weeding, and harvesting. The inventory data of this stage were obtained from Papong et al. (2014) (detailed as showed in the section 7.1), and they were verified against on-site data collection in Nakhonratchasima province, in the northeastern part of the country. The emissions to air from diesel combustion in the agriculture machinery and fertilizer application were calculated using the emission factor from the IPCC guidelines (IPCC, 2006) and the EEA guidebook (EEA, 2013).

7.2.2.3.1.2 Cassava chip production

The data on cassava chip processing were collected via on-site interviews with the Thai owners of the chip processing plants. Cassava chips are derived from the cassava root, the processing steps include; (1) cleaning the cassava root, (2) cassava root chopping, (3) sun drying the cassava chip, and (4) packing the dried cassava chips. At this stage, diesel is used for tractors and chopping machines estimated at 7 liters per ton of dried cassava chips. Air emissions from diesel combustion in the tractors and chopping machines were estimated using the emission factor from the EEA (EEA, 2013).

7.2.2.3.1.3 Cassava-based ethanol production

The process of producing bioethanol from cassava, a starch-based feedstock, consists of five main sub-processes: milling, mixing and liquefaction, saccharification and fermentation, distillation, and dehydration. After the distillation process, the non-fermentable solids remaining in distilled mash, termed stillage, are digested to produce biogas. This biogas produces energy in the form of steam used in the ethanol conversion process, substituting a portion of other energy sources. Electricity obtained from the grid is the other form of energy supply. The raw material for these ethanol factories were selected in this study is cassava chip. This study was divided into two case studies, as presented in Table 7-5. The emissions to air from the combustion of various fuels in the steam boiler and CH4 emissions from the wastewater treatment were calculated based on the emissions factors from the IPCC guidelines (IPCC, 2006) and the EEA guidebook (EEA, 2013).

The by-products from the production process includes fusel oil and cassava pulp, however, this study does not allocated environmental burdens to by-products due to the current ethanol plants in Thailand not yet utilizing these by-products. The main input-output data of cassava-based ethanol production process is shown in Table 7-6.

Table 7-5. The case studies of the cassava-based ethanol production in this work

Items	CE / Coal	CE / Coal & biogas	CE / Biomass	CE / Average
Feedstock	Cassava chip	Cassava chip	Cassava chip	Cassava chip
Factory type	Stand-alone factories	Stand-alone factories	Stand-alone factories	Stand-alone factories
Fuel use for steam production	Coal (100%)	Coal (79%) and biogas (21%)	Biomass (76%) and biogas (24%)	Coal (15%), fuel oil (12%), and biomass & biogas (73%)
Electricity	National grid	National grid	National grid	National grid

Table 7-6. Inventory data of ethanol production from cassava chip.

Items	Unit	CE / Coal	CE / Coal & biogas	CE / Biomass	CE / Average
Input					
Cassava chip	kg	2.41	2.41	2.31	2.41
Water	kg	11.25	11.25	11.25	11.25
Steam	kg	3.10	3.10	4.40	3.30
Electricity (grid)	kWh	0.30	0.30	0.26	0.29
Chemical	kg	0.022	0.022	0.024	0.022
Product					
Ethanol	L	1.000	1.000	1.000	1.000

7.2.2.3.1.4 Transportation of cassava-based ethanol system

In the cassava-based ethanol production system, all materials and products are hauled from various transport facilities over various distances. Data related to the transportation of main raw materials were gathered from actual sites in Thailand. The cassava root transport from farm to the cassava chip factories were estimated to the nearest 25 kilometers (km) by diesel truck with an 11 ton loading capacity. While, the cassava chip transport from the cassava chip plants to the cassava-based ethanol factories were approximated 130 km by diesel truck with 32 ton loading capacity.

7.2.2.3.2 Sugarcane molasses-based ethanol

The system boundary of the ethanol production from sugarcane molasses include the cultivation and harvesting of sugarcane, transport of the sugarcane to the sugar mill (molasses production), transportation of the molasses to the ethanol factory, and the ethanol production. The details of the molasses-based ethanol system are described in below.

7.2.2.3.2.1 Sugarcane plantation and harvesting

In 2015, the sugarcane planting area has a total of 1.76 million hectares with a production output of approximately 100 million tons of sugarcane. The average yield estimated 57 tons per hectares. The north-eastern sugarcane harvesting areas account for almost 45% of the country's production, followed by the central (26%), the north (24%), and the east (5%) region (OCSB, 2016). These are divided into green and burnt cane harvesting accounting for 35% and 65%, respectively. The green cane harvesting is the preferred harvesting technique due to the advantages in terms of reducing the environmental problems but this has been slow to be adopted. Burnt cane harvesting, on the other hand, is easier to harvest, but the effect on air pollution problems generating large amounts of particles and toxic gases. Although, 65% of the cane is burned before harvest, CO_2 emissions are generally equal to the amount of CO_2 that the plant takes up from the atmosphere during its growth stage.

At this stage, sugarcane cultivation steps include land preparation, planting, fertilizing, weeding, watering, and harvesting. Background information was obtained from various studies, but detailed information on fuel and material inputs was reviewed and verified by a field survey. The inventory data of sugarcane cultivation are presented in Table 7-7.

Table 7-7. Inventory data of sugarcane plantation in the study

Items	Unit	Amount
Inputs		
Diesel	liter	3.260
Fertilizer (N-P-K): 16-16-8	kg	5.700
Ammonium sulphate	kg	5.700
Glyphosate	kg	0.090
Atrazine	kg	0.090
Product		
Sugarcane	kg	1,000

7.2.2.3.2.2 Sugarcane milling

Sugar milling starts with crushing the cane to extract the juice, then impurities and excess water are removed, leaving a concentrated syrup. This liquid is boiled until sugar crystals appear, which are then separated from the syrup using a multi-stage centrifugal machines, to create molasses. Filter cake, the residue from the clarification of cane juice, can be used as soil conditioners in nearby farms. This study is considered as waste to soil conditioner in sugarcane farming, which is not to be treated. Bagasse, the fiber left after the sugar cane juice is extracted, is burned in a boiler to produce steam and electricity for the operation of sugar mills. In just some season, bagasse may not be able to produce enough for power. Some kinds of agricultural residue such as rice or wood husk burn were also used as a supplemental fuel in sugar milling to reduce fossil energy. However, if the electricity produced in excess of the mill demand, the mills can also sold to the grid.

Normally, sugar factories will produce plenty of wastewater in a day and they will have their own biomass power plant, and sometimes their own ethanol factory also. However, the factories do not discharge the wastewater out of the factories, instead it is treated and used for watering the sugarcane farms in the factories. The co-products and by-products obtained from the sugar production stage are molasses, surplus electricity, and surplus bagasse. In order to allocate the materials use, energy use, and environmental burden for the co-products in the sugar milling process; sugar content and market price were all used. The factors for allocating the environmental load of the molasses production from sugar milling and sugarcane cultivation were presented in Table 7-8.

The main input-output data of the sugar milling stages shown in Table 7-9 are not allocated yet. Products and co-product outputs from this stage that are considered in the analysis include: raw sugar, molasses, and surplus electricity. In addition, the output from bagasse combusted in a boiler to produce steam and electricity in sugar mill was calculated based on the IPCC guideline (IPCC, 2006) and the EEA guidebook (EEA, 2013).

Table 7-8. The allocation factors of molasses production from sugarcane.

Scenario	**Product and co-products**	**Quantity**	**Allocation factors**	
			Mass (Dried mass)	**Economic**
Business as Usual (BAU)	Sugar	1.00 kg	78.51%	89.21%
	Molasses	0.507 kg	21.49%	10.79%

Table 7-9. Inventory data of sugarcane milling (without allocation)

Items	**Unit**	**Amount**
Inputs		
Sugarcane	kg	1,000
Water	kg	46.00
Electricity from bagasse	kWh	14.74
Steam from bagasse	kg	573
Chemical	kg	8.50
Products		
Raw sugar	kg	108.50
Co-products		
Molasses	kg	55.00
Surplus bagasse	kg	37.10
Filter cake	kg	40.25
Electricity for sale	kWh	54.66

7.2.2.3.2.3 Molasses-based ethanol production

The production process consists of three main steps. First, molasses upon fermentation with yeast (in the presence of nutrients) yields dilute alcohol. Second, the fermented mash is pumped into the distillation system where the alcohol is removed from the non-fermentable solids and water. After passing distillation system, the alcohol product reaches about 95% concentration. Third, the 95% ethanol then goes to the dehydration stage, where nearly all the remaining water is removed to yield the 99.5% ethanol so call "anhydrous ethanol". The residue mash, or stillage, can be utilized for energy generation via the biogas pathway.

Ethanol production are generated various by-products such as CO_2 from the fermentation process and fusel oil from the distillation process. In case of fusel oil, its weight compared to ethanol is lower than 0.1% of the main product. Therefore, they are not included in the scope as part of the assumption. The inventory data for this sub-process, within the scope of the study, come from five factories as summarized in Table 7-10. The overall energy sources that are used in the molasses-based ethanol production mainly come from bagasse (for electricity generation from the sugar mill) and biogas (for steam production from their own facility).

Table 7-10. Inventory data of bioethanol production from molasses (without allocation)

Items	Unit	Amount
Inputs		
Sugarcane molasses	kg	4.35
Water	liter	12.92
Electricity from bagasse (sugar mill)	kWh	0.27
Steam from biogas (own facility)	kg	3.09
Chemical	kg	0.03
Product		
Anhydrous Ethanol (99.5%)	liter	1.000

7.2.2.3.2.4 Transportation of molasses-based ethanol system

All materials (fertilizers, pesticides, etc.), fuels (rice husk, diesel, etc.), products (sugarcane molasses), intermediate products (sugarcane stalks), and other elements involved in the life cycle of molasses-based ethanol are hauled by different transport companies across various distances. The data associated with this stage were estimated based on the distance between the agrochemical shops and farms, and the sugar mills and farms.

The sugarcane stalks transportation from farm to the sugar mills was estimated as 44 km by diesel truck with 21–36 ton loading capacity. While, the molasses transported from the sugar mills to the ethanol plants were estimated to travel 1 km via pipeline.

7.2.2.4 Direct land use change (dLUC)

In this study, the GHG emissions from dLUC considers only the land conversions from cropland due to the fact that deforestation is illegal in Thailand. The study was assumed the scenarios for estimated the dLCU effect on GHG as follows:

- Scenario 1: land conversion from perennial crop land to annual crop land;
- Scenario 2: land conversion from rice field areaa to annual crop land.

The GHG emissions from dLUC is calculated using the following 2006 IPCC guideline (IPCC, 2006), as shown in the equation (7-3). The emission factor for GHG calculation from the dLUC is presented in Table 7-11.

$$\Delta C_{LU} = \Delta C_{biomass} + \Delta C_{DOM} + \Delta C_{soil} + L_{fire} \qquad (7\text{-}3)$$

ΔC_{LU} = Carbon stock change for land use (tonnes CO_2eq $ha^{-1}yr^{-1}$)

$\Delta C_{biomass}$ = Annual change in carbon stocks in biomass (the sum of above-ground and below ground biomass) considering total area (tonnes CO_2eq $ha^{-1}yr^{-1}$)

ΔC_{DOM} = Annual change in carbon stocks in dead wood of litter (tonnes CO_2eq $ha^{-1}yr^{-1}$)

ΔC_{soil} = Annual change in carbon stocks in soil (tonnes CO_2eq $ha^{-1}yr^{-1}$)

Table 7-11. GHG emission factor from dLUC (unit: t CO_2 eq/ha-yr)

dLUC type	$\Delta C_{biomass}$	ΔC_{DOM}	ΔC_{soil}	L_{fire}	Total
Perennial crop land to annual crop land	2.638	0.000	3.481	0.108	6.227
Rice field land to annual crop land	0.000	0.000	1.282	0.038	1.320

Based on Thailand's statistical data of 2014, the total cultivation areas of cassava and sugarcane are 1.44 and 1.35 million hectares, respectively. Whereas, the cultivated areas of both in 2005 are 1.04 and 1.07 million hectares, respectively. These are increasing by 0.30 and 0.28 million hectares, respectively (OAE, 2015). The yield from the cassava root in 2014 was 22 tonnes per hectare, so one tonne of cassava root will require 0.045 hectares-year. While sugarcane yield is 57 tonnes per hectare, one tonne of cane will require 0.018 hectare-years. The GHG emissions from the dLUC of each scenario as shown in Table 7-12.

Table 7-12. GHG emissions from the dLUC type of cassava and sugarcane cultivation duration 2008-2014 (unit: kg CO_2eq per tonne)

dLUC type	Cassava	Sugarcane
Scenario 1: Perennial crop land to annual crop land	66.27	25.08
Scenario 2: Rice field land to annual crop land	13.88	5.25

7.2.2.5 Water footprint (WF) analysis

7.2.2.5.1 WF of the crop cultivation stage

WF of the crop cultivation is estimated by following the water footprint network manual. To determine the crop water requirement (CWR), the CWR are calculated by the crop coefficient (K_c) multiply by the reference crop evapotranspiration (ET_0), the Equations (7-4). The green evapotranspiration (ET_{green}) and blue evapotranspiration (ET_{blue}) of the crops are calculated by Equation (7-5) and Equation (7-6), respectively. WF_{green} and WF_{blue} are calculated by following Equation (7-7) and Equation (7-8), respectively.

$$CWR = K_c \times ET_0 \ (mm/day) \quad (7\text{-}4)$$

$$ET_{green} = min\ (CWR, P_{eff}) \quad (7\text{-}5)$$

$$ET_{blue} = max\ (0, CWR – P_{eff}) \quad (7\text{-}6)$$

$$WF_{green} = 10 \times \sum_{d=1}^{cgp} ET_{green} \Big/ Y \quad (7\text{-}7)$$

$$WF_{blue} = 10 \times \sum_{d=1}^{cgp} ET_{blue} \Big/ Y \quad (7\text{-}8)$$

where ET_0 is the reference Penman-Monteith crop evapotranspiration [mm/day]. ET_0 for each province was gathered from the Royal Irrigation Department of Thailand (RID, 2011). The RID of Thailand has estimated ET_0 by using the monthly climatological data of Thailand for the 30–year period (1981–2010), this climate data gathered from the Thai Meteorological Department (TMD, 2013). K_c is the crop coefficient of each crop type. The crop coefficient for cassava and sugarcane is adopted from the FAO (1998) and RID (2011), respectively. P_{eff} is effective rainfall, which as data gathered from the RID (2011). If CWR is more than the effective rainfall (P_{eff}), green WF of the crop will be equal to the Peff. However, if CWR is less than effective rainfall, green WF of the crop will be equal to CWR. Blue WF of the crop is defined as the irrigation water which needed to fulfill the crop evapotranspiration if the effective rainfall is not sufficient. If CWR more than P_{eff}, blue WF of the crop = CWR – P_{eff}, whereas, if CWR less than P_{eff}, blue WF of the crop = 0. The crop growing periods (cgp), and amount of the crop production (Y) in each province are obtained from the Office of Agricultural Economics (OAE, 2016). It should be noted that the CWR of crops calculated is based on the water requirement theory. Equation (4) and Equation (5) show the formula to calculate the green and blue WF of crop, respectively. The factor 10 is used to convert from millimeters into the volume of water per land area (m^3/ha). The total water consumption will be calculated cover from the day of planting (day=1) to the day of harvest (cgp is the crop growing period in days). Y is the production yield of each crop.

7.2.2.5.2 WF of the industrial stage

The water consumption of seven ethanol factories was gathered from four molasses-based ethanol, and three cassava-based ethanol plants. The average input and output data are shown in the section 7.2.3. In this study we only considered the direct water consumption in the ethanol plants due to lack of data on the indirect water consumption of material input.

7.2.2.6 Social impact analysis

The social indicators selected in this study are the employment generation, wages, and fatal occupational health and safety. In this study, we use the hybrid approach by combining the process-based approach (site specific data) and top-down approach (input-output analysis), to evaluate the employment, wages, and fatal occupational injury impacts of bioethanol production, in Thailand.

7.2.2.6.1 Direct employment, wages, and fatal occupational injury in the agricultural stage

For the direct employment, wages, and occupational injury effects on the agriculture stage in this study, we collected data about the number of employees, wage rates, and accidents in farming in combination with the cultivation area and production yields from the 300 farmers in top five provinces, which are highest planting area. The expenditures relating to labor costs for land preparation, planting, fertilizing, weeding, and harvesting are gathered from interviews and previous studies. To determine the amount of direct employment in cultivation and harvesting the labor costs data in farming can be divided by the average worked hours in agricultural sector.

7.2.2.6.2 Direct employment, wages, and fatal occupational injury in the industrial stages

To determine the direct employment, wages, and occupational accidents in the workplaces of the industrial stages (feedstock processing and bioethanol production), we collected the data on the number of workers, wage rate, the number of fatal occupational injuries, and the production capacities from 5 sugar factories, 5 dried-chip plants, and 5 ethanol plants. The direct employment, wages, and fatal occupational injuries relating to the industrial stages in bioethanol production in this study are presented in Table 8.

7.2.2.6.3 Indirect employment and occupational injury analysis

This study used the input–output analysis to evaluate the social footprints embodied in the bioethanol system. We used the 2005 Thailand IO table for evaluating the social impact that consists in 180 economic sectors, aggregated to 96 sectors based on the social intensity data from Papong et al. (2015). This part had already explained in the section 7.1.2.4.3.

7.2.3 Results and discussions

7.2.3.1 GHG emissions

Figure 7-11 shows the GHG emissions of cassava-based and molasses-based ethanol production from cradle-to-gate in comparison with previous studies. The worst case scenario of GHG emissions of the CE system is the CE/coal case study accounting for 98.8 kg CO_2 eq. per GJ ethanol, due to coal combustion in a boiler and CH_4 emission from the wastewater treatment process. An average GHG emissions of CE (CE/average) from cradle-to-gate accounting for 37.3 kg CO_2 eq. per GJ ethanol and the best case (CE/biomass) which is the ethanol factory use biomass as fuel for steam production, is about 27.2 kg CO_2 eq. per GJ ethanol. It can reduce GHG emissions 72.5% and 27.1% when compared with the worst case and an average case, respectively. The GHG emissions in the CE/average case are mainly due to coal combusted for steam production in the ethanol conversion process, followed by cassava cultivation due to N_2O emission from N-fertilizer application. For the MoE production system, the GHG emissions accounted for 39.0 kg CO_2 eq. per GJ if the sugar content is used for allocating (MoE/SC) the environmental burden between molasses and raw sugar. Whereas, if we used the market price for allocation (MoE/EC) of both products, the GHG emissions reduced to 25.7 kg CO_2 eq. per GJ, or equivalent to a 34.2% reduction. The GHG emissions of the MoE systems are mainly due to N_2O emission from N-fertilizer applications in the cultivation stage and the emission from the sugarcane burning before harvesting.

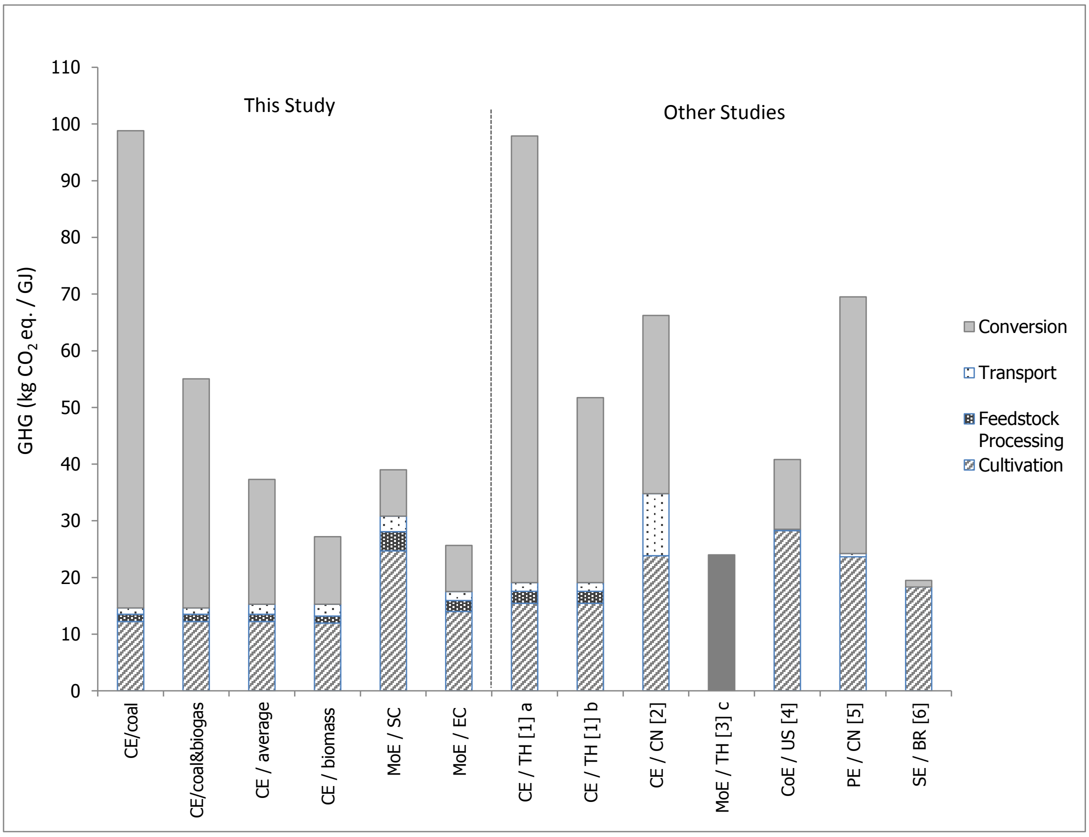


Figure 7-11. Comparison the GHG emissions of CE and MoE of this study and other studies.

[1] Cassava ethanol (CE) in Thailand from Moriizumi et al. (2012), a – based on coal as fuel, b – based on coal and biogas as fuel; [2] cassava ethanol in China from Liu et al. (2013); [3] molasses ethanol in Thailand from Silalertruksa et al. (2016), c – included cultivation, feedstock processing, transport and conversion; [4] Corn ethanol in USA from Liska et al. (2009); [5] potato ethanol in China from Wang et al. (2013); [6] sugarcane ethanol in Brazil from Khatiwada et al. (2012)

When comparing the GHG results of the CE system of this study with a similar study in Thailand (Moriizumi et al., 2012), and a similar study in China (Liu et al., 2013), they reported GHG emissions of 51.8–97.9 kg CO_2 eq. per GJ ethanol. Previous studies are higher than the average and best case value obtained in our study, which was 27.2–37.2 kg CO_2 eq. per GJ. The main difference was that both Moriizumi et al. (2012) and Liu et al. (2013) studies were considering the steam boiler using sub-bituminous coal at the ethanol plant, which contributes more than 60% of the total GHG impact. While the average case studies selected in this study were evaluated for their environmental impacts, based on the production capacity of the ethanol plants, including the factory's use of imported bituminous coal as fuel (12%) and the factory's uses of biomass and biogas as fuel (88%). However, when comparing the worst case of this study with previous studies, the results are a similar range. The second impact comes from the cassava cultivation stage, which contributes more than 33% of the GHG emissions. In this stage, the GHG emission of this study were similar to the previous studies in Thailand, but lower than a case study in China due to fertilizers and pesticides inputs of this study being lower than that of others. In addition, if we compared this with the potato ethanol (PE/CN) produced in China, the GHG emissions of this study are lower than that of PE/CN due to the case studied in China that used coal as fuel in the conversion process. When comparing with corn ethanol (CoE/US) produced in the USA, the result showed that the CE had lower GHG emissions than CoE due to the corn cultivation stage having higher fertilizer inputs with lower yield and in the corn ethanol production process using natural gas as fuel in the boiler.

When comparing the GHGs emissions of MoE system of this study with a similar study in Thailand (Silalertruksa et al., 2016), they reported GHG emissions of 24.0 kg CO_2 eq. per GJ ethanol. Based on economic allocation approach in the sugar mills along with supply chain, the value of our study (MoE/EC) is higher than in the study by Silalertruksa et al. where about 6.5% was due to the same approach for allocation the environmental burden. Based on the sugar content allocation approach (MoE/SC-A), the GHG value obtained in our study, was 35.5 kg CO_2 eq. per GJ. The main difference due to the allocation approach based on sugar content in sugar mills had about a 2 times higher environmental burden than the economic allocation. When compared to the sugarcane-based ethanol in Brazil (SE/BR) studied by Khatiwada et al. (2012), they reported the GHG emissions of 19.5 kg CO_2 eq. per GJ, which was lower than the value obtained in this study. Because the case studied based on sugarcane had been sufficient energy from bagasse for ethanol conversion process, which the CO_2 from bagasse combustion was carbon neutral. While, the molasses ethanol conversion process of this study accounted for methane leakages from the biogas production whilst producing steam used in the process.

7.2.3.2 Acidification potential (AP)

Figure 7-12 shows the AP impact category of bioethanol production from cassava and molasses from cradle-to-gate of this study in comparison to previous studies. When comparing between the worst case scenario (CE/Coal) and an average case of CE system, the result shows that the AP impact of the average case is lower than the worst case of approximately 60.4%, due to the high SO_2 emission from coal combustion in a steam boiler. An average AP emission of the CE (CE/average) accounting for 0.23 kg SO_2 eq. per GJ ethanol and the best case (CE/biomass), which is the ethanol factory use biomass as fuel for steam production, of about 0.22 kg SO_2 eq. per GJ ethanol. It shows that the AP impact of the best case is less than the average cases of only 3%. The AP impact of the CE/average case is mainly due to SO_2 and NO_x emissions from coal combusted for steam production in the ethanol plants. In addition, the impact of the CE/biomass case is mainly from high NO_x emission from biomass combustion in a steam boiler. For the MoE production system, the AP emissions of the MoE/SC-A case studies account for 0.34 kg SO_2 eq. per GJ. Whilst, the MoE/EC-A case studies, the AP emissions are generated at 0.23 kg SO_2 eq. per GJ, or a 31.8% reduction. The AP impact of the MoE system is mainly due to the NO_x emission from the cane trash burning before harvesting, and bagasse combustion in the boiler for producing steam and power in the sugar mills.

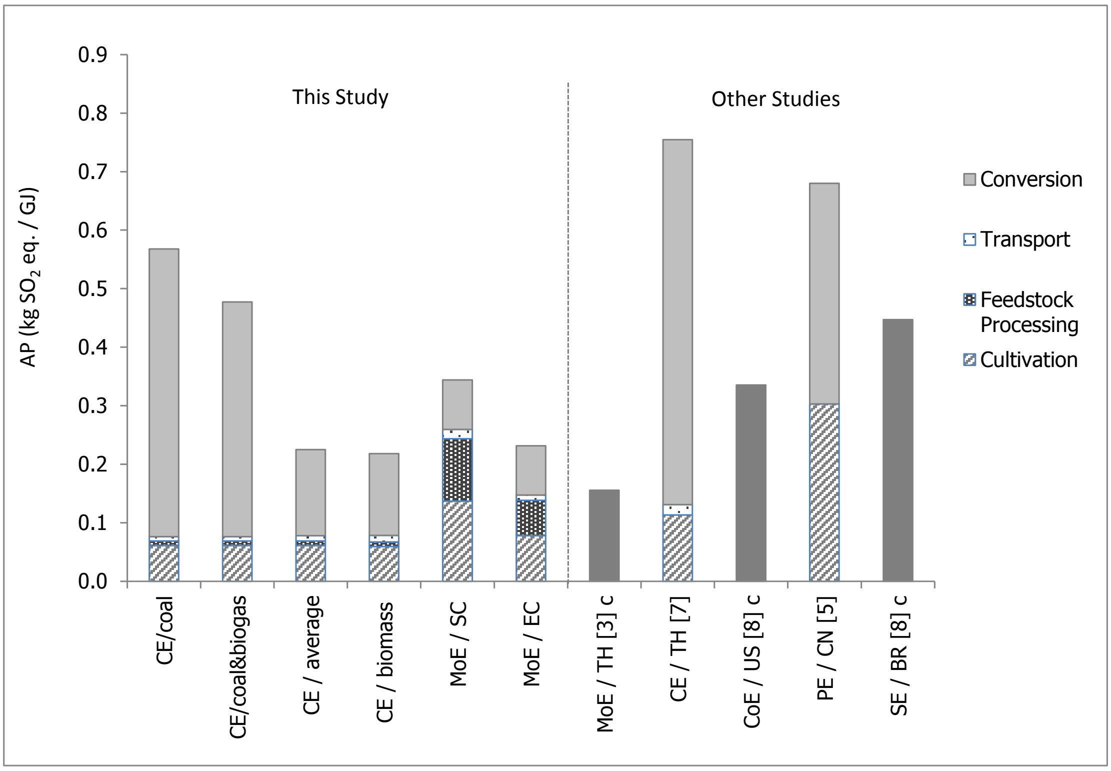


Figure 7-12. Comparison the AP impact of CE and MoE of this study and other studies.

[3] molasses ethanol in Thailand from Silalertruksa et al. (2016), c – included cultivation, feedstock processing, transport and conversion; [5] potato ethanol in China from Wang et al. (2013); [7] cassava ethanol in Thailand from Silalertruksa and Gheewala (2009); [8] corn ethanol in USA and sugarcane ethanol in Brazil from Muñoz et al. (2013)

When comparing the AP results of the average case and best case of CE system of this study with a similar study in Thailand by Silalertruksa and Gheewala (2009), they reported AP of 0.76 kg SO_2eq. per GJ. Their studies are higher than the value obtained in our study, which was 0.22–0.23 kg SO_2eq. per GJ. The main difference for the CE system was that Silalertruksa and Gheewala (2009) considered the steam boiler using sub-bituminous coal at the ethanol plant, which contributes more than 80% AP of the total impact. While this study has only 12% of production capacity that contributed to the ethanol factory used coal as fuel in a boiler. If we compared the AP impact with the PE/CN that were conducted by Wang et al. (2013), the result of this study was lower than that of the PE/CN due to the case studies in China using coal as the fuel in boiler. In addition, when comparing with the CoE/US (Muñoz et al., 2013), the result showed that CE had a lower AP impact than CoE due to the corn cultivation stage having a higher fertilizer input.

For the MoE system, comparing the AP result of this study with a case study in Thailand by Silalertruksa et al. (2016), they reported an AP impact of 0.16 kg SO_2 eq. per GJ ethanol. The AP impact of our study is a higher than the result of Silalertruksa et al. (2016) due to the higher ratio of the burnt cane harvesting (65% of cane used in the sugar mills). The burning of sugarcane before harvesting generated large amounts of the acidifying substances such as SO_2 and NO_x. In addition, the AP impact of MoE of this study is lower than that of sugarcane ethanol in Brazil (Muñoz et al., 2013). The main difference due to the ratio of pre-harvesting burning of sugarcane by 70% in Brazil and the chemical fertilizer application rate in Brazil has higher than that of.

7.2.3.3 Eutrophication potential (EP)

Figure 7-13 shows the EP impact category of the CE and MoE systems, from cradle-to-gate of this study, in comparison with other studies. The EP impact of the worst case scenario, CE/average case, and best case of the CE study accounted for 0.0066, 0.0064, and 0.0058 kg P eq. per GJ, respectively. It shows that the EP impact of the best case is around 12.0% and 9.3% less than the worst case and the average cases, respectively. The EP impact of the CE system is higher in the ethanol production stage due to wastewater generated during the production process. While in the cassava cultivation stage it is mainly as a result of nitrate leaching of fertilizer applications and fertilizer production. The EP impact of the MoE/SC-A case generated 0.0007 kg P eq. per GJ, while the MoE/EC-A case studies generated 0.0005 kg P eq. per GJ. The minus value in the molasses production stage is due to the credit from the surplus bagasse electricity exported to the national grid. The EP impact of the MoE system is higher in the sugarcane cultivation stage mainly from the nitrate leaching from fertilizer applications and fertilizer production.

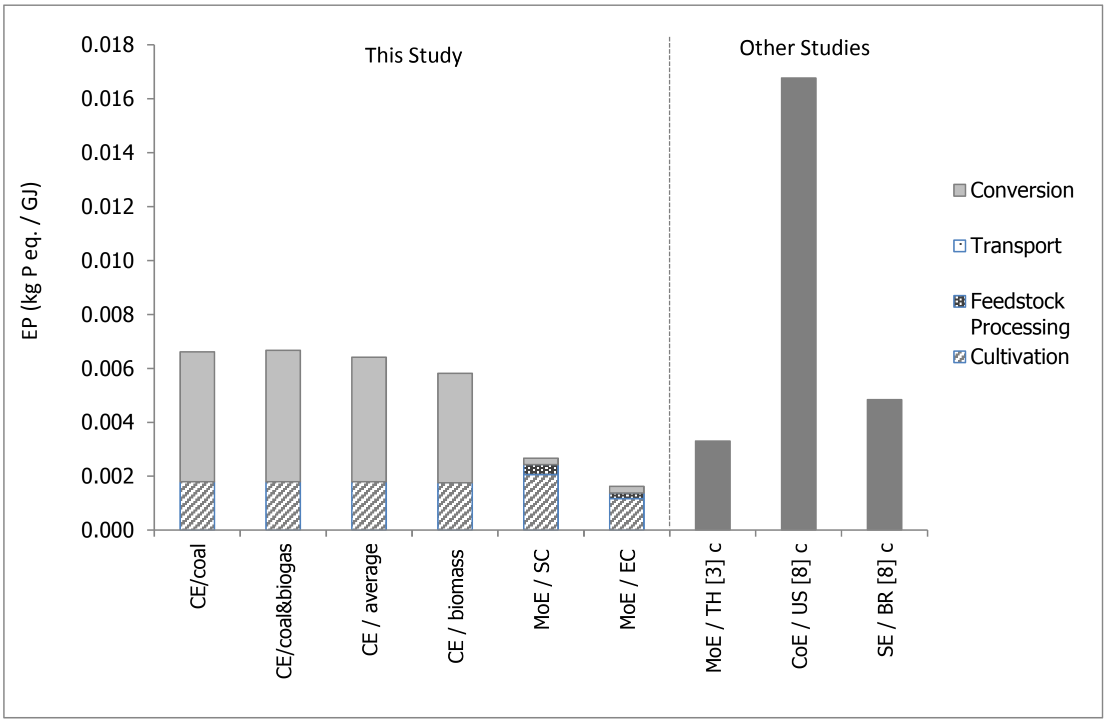


Figure 7-13. Comparison the EP impact of CE and MoE of this study and other studies.

[3] molasses ethanol in Thailand from Silalertruksa et al. (2016), c – included cultivation, feedstock processing, transport and conversion; [8] corn ethanol in USA and sugarcane ethanol in Brazil from Muñoz et al. (2013)

When comparing the EP results of the CE system of this study with the corn ethanol in USA studied by Muñoz et al. (2013), they reported an EP of 0.017 kg P per GJ. These studies are about 2.6–2.9 times higher than the value obtained in our study. The main difference is due to the N-fertilizer application rate in cultivation stage of corn ethanol in the USA being about 3 times higher than the cassava cultivation in this study. For the MoE system, the EP impact of this study had lower than that the result of Silalertruksa et al. (2016) about 4–6 times. The major difference is the allocation approach in the analysis of Silalertruksa et al. (2016) study that used the economic value for dividing the environmental burden between raw sugar, refined sugar, molasses, surplus electricity, and bio-fertilizer. While our study only considered raw sugar, molasses, and surplus electricity exported to the grid.

7.2.3.4 Human toxicity potential (HTP)

Figure 7-14 shows the HTP impact category of the CE and MoE systems from cradle-to-gate of this study, in comparison with other studies. The HTP impact of the worst case scenario (CE/coal), CE/average cases, and best case of the CE study accounted for 6.53, 6.01, and 6.15 kg 1,4-DB eq. per GJ, respectively. It shows that the HTP impact of the average case is less than the worst case of 8% due to the toxic emissions from coal combusted in a steam boiler, whereas the best case is higher than the average cases of around 2% due to agrochemicals used in the wood plantation. The HTP impact of the CE system is mainly due to coal and biomass combusted for producing steam in the ethanol conversion process. In addition, the biomass plantation is also the major cause of the HTP impact due to fertilizers used in plantation stage. The HTP impact from the cassava cultivation stage is due to the production of N-fertilizer. The HTP impact of the MoE/SC-A and MoE/EC-A case studies generated 3.11 and 2.22 kg 1,4-DB eq. per GJ, respectively. The HTP impact of the MoE system comes from the production of chemical fertilizers such as ammonium sulphate, urea, and diammonium phosphate.

When comparing the HTP results of the MoE systems in this study with a similar study in Thailand by Silalertruksa et al. (2016), the result showed that HTP of our study is lower than that of the previous study. The major difference is due to the ratio of the cane burning before harvesting as of our study is lower than the previous studied.

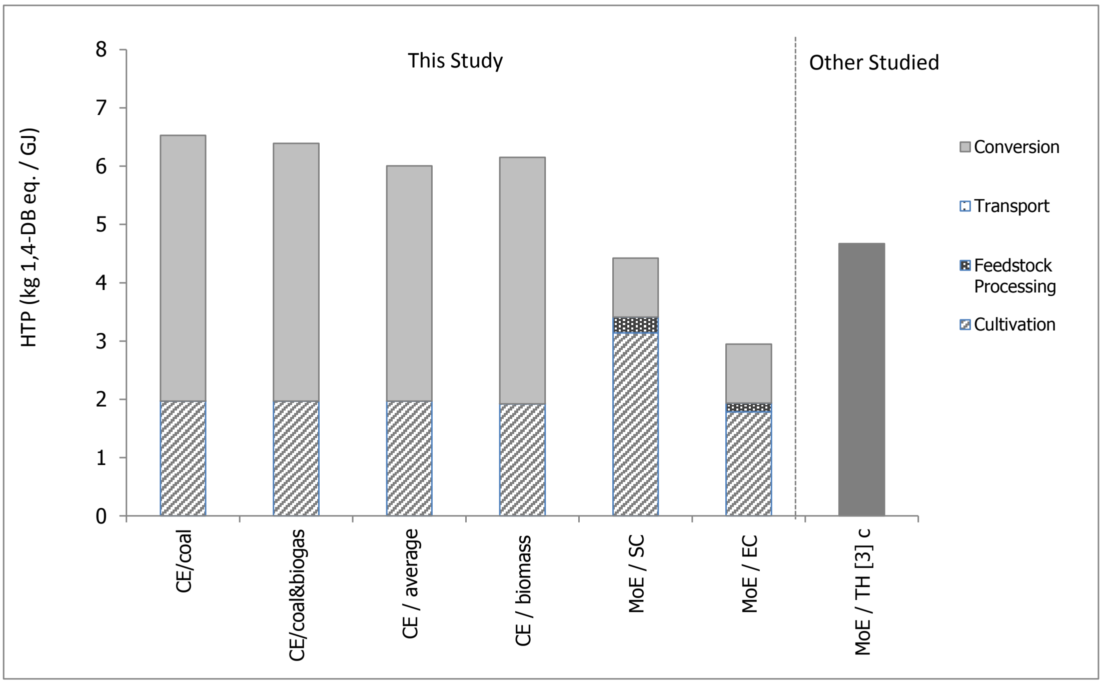


Figure 7-14. Comparison the HTP impact of CE and MoE of this study and other studies.

[3] Molasses ethanol in Thailand from Silalertruksa et al. (2016), c – included cultivation, feedstock processing, transport and conversion

7.2.3.5 GHG emissions from direct Land use change

When considering the GHG emissions due to the direct land use change, based on one GJ of cassava, ethanol the GHG emission from dLUC is 20.68 (S1) and 4.38 (S2) kg CO_2 eq. For molasses-based ethanol, the case study based on economic allocation generated 10.21 (S1) and 2.16 kg CO_2 eq. per GJ, whereas if we used the sugar content for allocation the GHG generated to 17.98 (S1) and 3.81 (S2) kg CO_2 eq. per GJ. The results are presented in Table 7-13. In the case of CE system, this study was only considered the average case and best case scenarios.

Table 7-13. Comparing the GHG emissions of ethanol from cassava and molasses including the dLUC effects (unit: kg CO_2 eq. per GJ).

dLUC Scenario	Cassava-based ethanol		Molasses-based ethnaol	
	CE/average	CE/biomass	MoE/SC	MoE/EC
Scenario 0 (exclude dLUC)	37.20	27.20	36	23
Scenario 1	57.88	47.88	53.98	40.98
Scenario 2	41.58	31.58	39.81	28.81
Corn-based ethanol (Tyner et al., 2010)[1]	84.4			
Corn-based ethanol (Tyner et al., 2010)[2]	81.3			
Corn-based ethanol (Tyner et al., 2010)[3]	78.1			

[1]Land use change simulation based on the 2001 database

[2]Land use change simulation based on the update 2006 database

[3]Land use change simulation based on the update 2006 database and with population and yield growth after 2006

If we compared the result with corn-based ethanol in USA to that studied by Tyner et al. (2010), the results show that the GHG emissions included dLUC of our study had lower than that of the Tyner et al. studied. The major different due to the dLUC result of Tyner et al. was based on the landuse conversion from forestland (35%) and grassland (65%).

7.2.3.6 Water Footprint Analysis

Water use of cassava and sugarcane cultivation varies in the different regions. From the results, it has shown that the yield, climate, and soil have an effect on water use of bioethanol. This study estimated the green water footprint (WF) and the blue WF, the result shows that the total WF of cassava ethanol and molasses ethanol accounted for 111–114 and 79–138 m^3 per GJ ethanol, respectively (Table 7-14). When comparing this result with a similar study in Thailand conducted by Gheewala et al. (2014), they reported WF of cassava and molasses ethanol ranged 112–134 and 93–142 m^3 per GJ, respectively. In addition, Gerbens-Leenes et al. (2008) and Mekonnen and Hoekstra (2011), reported WF of cassava ethanol is 138 and 120 m^3 per GJ ethanol, respectively. However, all previous studies have only considered the agricultural stage with irrigated agriculture system, and excluded grey water footprint, whereas our study considered both agriculture (rainfed system) and industrial stage. Furthermore, in the Gheewala et al. (2014), Mekonnen and Hoekstra (2011), and Gerbens-Leenes et al. (2008) studied were not considered in calculating the volume of blue water consumed in the process of industrial manufacture of cassava chip production and ethanol conversion.

Table 7-14. Green and blue water footprint of ethanol production from cassava and molasses

Stage	CE/Avg (m^3/GJ)			MoE/SC (m^3/GJ)		
	Green	Blue	Total	Green	Blue	Total
Agriculture	113.47	0.00	113.47	101.22	35.82	137.04
Raw material processing	0.00	0.00	0.00	0.00	0.12	0.12
Ethanol conversion	0.00	0.53	0.53	0.00	0.60	0.60
Total	113.47	0.53	114.00	101.22	36.53	137.76
Stage	CE/Biomass (m^3/GJ)			MoE/EC (m^3/GJ)		
	Green	Blue	Total	Green	Blue	Total
Agriculture	110.66	0.00	110.66	57.50	20.35	77.84
Raw material processing	0.00	0.00	0.00	0.00	0.12	0.12
Ethanol conversion	0.00	0.53	0.53	0.00	0.60	0.60
Total	110.66	0.53	111.19	57.50	21.06	78.56

In this study, we calculated an average WF of bioethanol system based on the CE/average (27%) and MoE/EC (73%). Then, the average WF of bioethanol is 88 m^3 per GJ ethanol. If we only considered blue WF, the result shows that the total WF of cassava and molasses ethanol is 0.53 and 21.06–36.53 m^3 per GJ ethanol, respectively. The blue WF of cassava ethanol in this study is lower than molasses ethanol due to cassava farming in Thailand in the rain-fed system. Based on the CE/average (27%) and the MoE/EC (73%), the average green WF of bioethanol is 105 m^3 H_2O per GJ, whereas the average blue WF is 15 m^3 per GJ ethanol.

Water impact potentials from bioethanol production

This study used the water stress index (WSI) of Thailand, gathered from Gheewala et al. (2014). The minimum value of the Thailand WSI is 0.012 in the Peninsular-West coast basin, whereas the maximum value is 0.927 for the Mun basin in the north-eastern area of the country. Based on the bioethanol factory locations in this study, these cover 10 provinces and 5 major watersheds, including the Mun, Chi, Chao Phraya, Pasak, Thachin, and Bang Pakong watersheds. Table 7-15 presents the water impact potentials from consumptive water use to produce one GJ of ethanol in the different ethanol factory locations.

Table 7-15. Water impact potentials of cassava-based and molasses-based ethanol production in this study.

Related watersheds	Provinces	WSI[1]	Water impact potentials (m^3 H_2O eq./GJ ethanol)		
			CE	MoE/SC	MoE/EC
Mun	Nakhonratchasima, Ubon Ratchathani	0.927	0.491	33.863	19.523
Chi	Khon Kaen, Chaiyaphum	0.471	0.250	17.206	9.919
Chao Phraya	Suphanburi	0.339	0.180	12.384	7.139
Thachin	Suphanburi, Nakornpathom	0.287	0.152	10.484	6.044
Pasak	Saraburi, Lopburi	0.050	0.027	1.827	1.053
Bang Pakong	Sakao, Chachoengsao, Chonburi	0.026	0.014	0.950	0.548

The result showed that the CE and MoE produced from the watersheds that is highly the WSI value would be also high water impacts. Bioethanol plants were located in the Mun, Chi, Chao Phraya, and Thachin watersheds where there is a higher water impact than the ethanol plants in the other watersheds. The indicator of water impact can be utilized for water planning and management in each watershed area to sustain the water management.

7.2.3.7 Socio-economic impact

7.2.3.7.1 Impact on paid worker employment

Figure 7-15 showed the direct and indirect employment generated by bioethanol production in Thailand. The results showed that the CE and MoE system generated the total employment of 5.5E-03 and 5.0E-03 persons per GJ, respectively. Direct employment in the cassava cultivation provides the most employment benefits contributing more than 58% of the total employment generated in the CE system. While for molasses-based ethanol, the molasses are allocated from the sugar sector in the IO tables using the market price, the total employment generated from this study will comprises the large employment in sugarcane cultivation accounting for 65% of total employment in the MoE production system. The high employment in agriculture indicates that the bioethanol promotion policy actually helps the rural area development in Thailand. In addition, in the developing countries such as Thailand, the agriculture sector is a higher labor intensity due to the cultivating systems are normally performed on the small scale farming and almost manual operation practices. The results of this study are similar to the previous study conducted by Silalertruksa et al. (2012), and Martínezetal et al. (2013). When comparing with sugarcane ethanol in Brazil, the result found that the employment generated from bioethanol of our study is approximately 2.7-3.5 times higher than case studied in Brazil. Due to the sugarcane farming in Brazil was operated by the mechanized farming system, whereas the agricultural stage in Thailand was small farmers and usually manual operation practices. However, workers in the agricultural sector is mostly performed by daily and seasonal employment who are low-skilled and working under poor conditions. Generally, labors in farming are related to family workers and own-account workers. When comparing the employment creation between THIO and AIIO database, the result found that the employment generated of cassava-based ethanol based on THIO is 9% higher than the AIIO. Due to the THIO was high resolution sectoral than the AIIO and all cassava feedstock was produced in the domestic. While the employment generated of molasses-based ethanol based on the AIIO is 18% higher than the THIO. Due to molasses are a by-product from sugar milling and the effect of machinery used in sugar mills which imported from other countries. However, both cassava and molasses feedstocks can produce in the country, thus the results from the THIO is a better than the AIIO.

Based on the total employment aspects, bioethanol production requires about 15–18 times more workers than conventional gasoline.

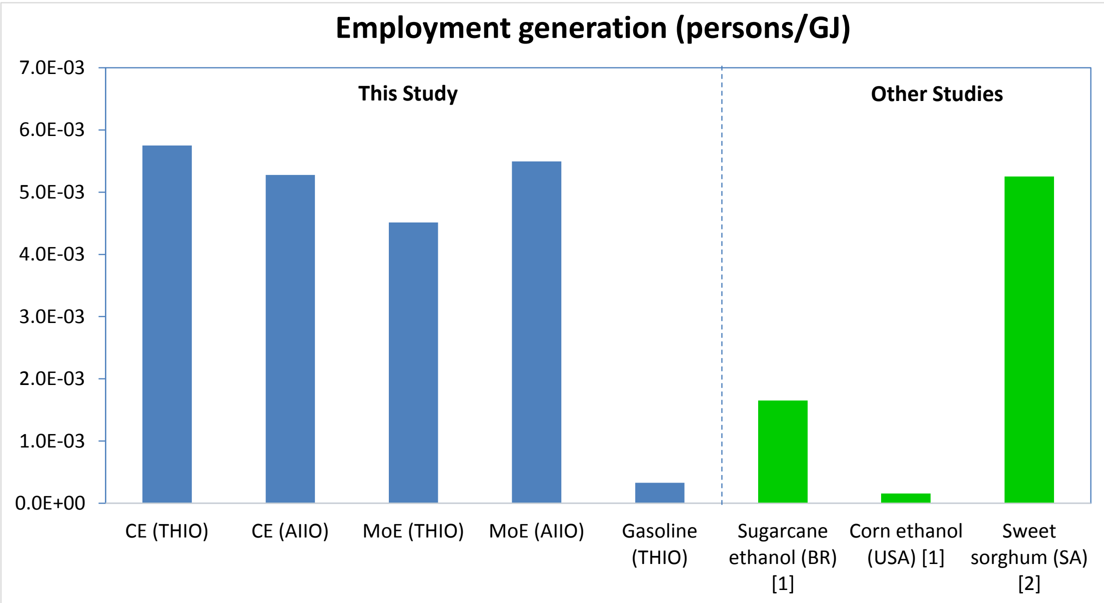


Figure 7-15. Comparison the total employment of bioethanol and gasoline.

Remark: [1] International Renewable Energy Agency (IRENA) (2014); [2] Sustek (2011) – case study in South Africa

7.2.3.7.2 Impact on wages

The wage impacts demonstrate how much wages would increase in the industrial sectors due to the bioenergy policy implementation. The direct and indirect wage impacts of bioethanol production in Thailand is presented in Figure 7-16. The overall impacts of the bioethanol production ranges from to 5.1 to 7.5 US$ per GJ ethanol depending on the feedstock for the bioethanol production. The wage impacts produced by bioethanol are the highest in the agriculture stage, approximately 30-45% of the total wage impacts. The smaller wage impacts are the direct compensation of employees in the ethanol factories. When comparing the wage paid to employees, the whole bioethanol supply chain has higher wages than conventional gasoline. This aspect is due to the wage rate in the agriculture sector in Thailand being lower than other sectors, but it should also be noted that the educational level of agricultural workers is very low (NSO, 2013) and very much higher labor intensity than the petroleum refinery sector. From the statistical data of Thailand on the wage rate between 2011 and 2015 period found that the average wage of labors in agriculture sector was increased by 18.8%, while the non-agriculture sector increased by 33.6%. The increasing of the wages in agriculture sector came in the form of a minimum wage rate, which was 100% during 2011–2015 period (Ministry of Labour, 2015).

Based on the wages aspect, bioethanol production supply chain paid the compensation about 14–21 times more wages paid than conventional gasoline.

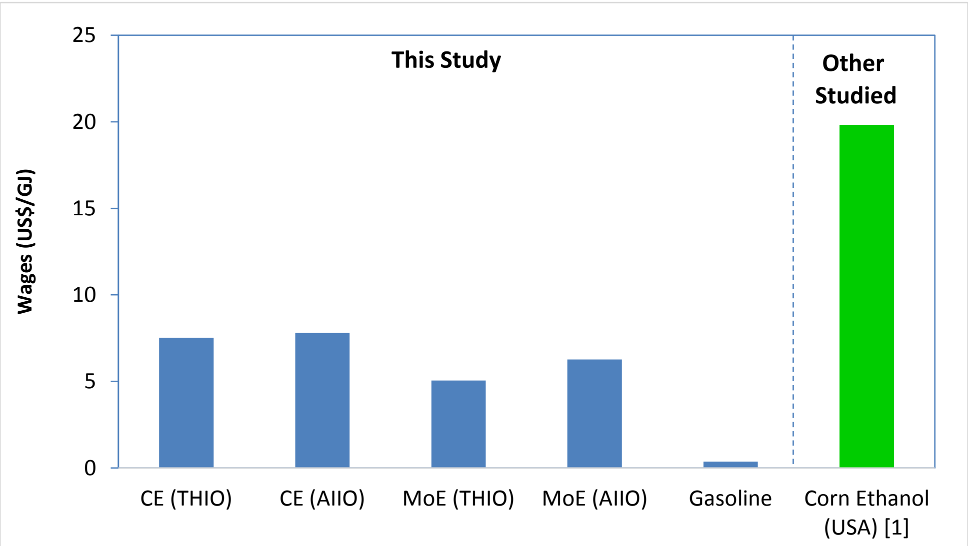


Figure 7-16. Comparison the wage paid to employees of bioethanol and gasoline.

Remark: [1] Corn ethanol of USA calculated using the data from Urbanchuk (2014).

7.2.3.7.3 Impact on fatal occupational injuries

The direct and indirect fatal occupational health and safety caused by bioethanol production in Thailand are estimated as shown in Figure 7-17. Based on the primary data from on-site survey in the period 2014, the cassava and sugarcane cultivation stage, and the CE and MoE factories in Thailand had not encountered a direct fatal accident in the workplace. There are no the fatal accident in the agriculture sector due to the farming operation systems in Thailand as they are generally carried out by the small scale farmers in less mechanized operations. According to an interview with the plant safety managers and employees in bioethanol factories, there're no recorded fatal accident cases in any of the factories. Therefore, all cases are recoded the non-fatal accidents. In addition, we found that the employees in the ethanol plant have been trained an average 5.0 hours/person/year in the health and safety in the workplace, which is higher than the reference value is 1 hour/person/year (Ministry of Labour, 2015).

The significant fatal accident in other sectors denotes that the policy to promote bioethanol and encourage health and safety at workplace helps to sustainable development in Thailand. If we considered the workers in related sectors to bioethanol production, it's possible the worker in the machinery manufacturing, basic chemical production, and power generation sectors could have higher possibilities of fatal occupational injuries. The high risk of injuries in these sectors may be related to a lack of training for the duties and safety workplace accidents. However, numbers of deaths per 100000 workers in Thai economic sectors have decreased by 39.1% over the period 2005–2015 (SSO, 2015). This result was caused by the continuous improvement of the occupational health and safety in the workplace. At present, the government has published the Occupational Safety, Health and Environment Act, A.D. 2011 (Ministry of Labour, 2015).

When comparing the embodied fatal occupational injuries between bioethanol and gasoline, the result showed that the bioethanol supply chain has higher risk than that of gasoline. Due to the security system and safety standard in the oil refinery sector are very much higher than other sectors.

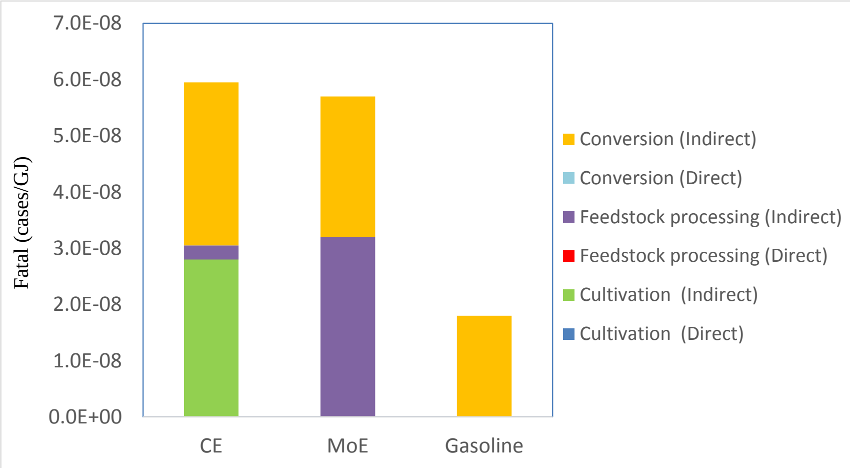


Figure 7-17. Comparison the fatal accidents in the workplace of bioethanol and gasoline.

7.2.3.8 Suggestions for improvement of bioethanol production system

The bioethanol production process can be improved on and developed to be more efficient by using pinch analysis to optimize the energy consumption of the overall processes. From the results of this study, the significant factor which affected to the GHG value of CE production was coal combusted in steam boiler and electricity consumption. We suggest that if the ethanol plant a decision is being made to replace a boiler system with a CHP system it has benefited both the economic and environmental. Because CHP consumes less fuel to produce each unit of energy output, and the CHP further reduces emissions.

For the MoE system, if the ethanol factories can utilize the wastewater, which is high COD to produce bio-fertilizer, it can reduce the environmental impact. In addition, the significant factor which affected to the GHG value of the MoE production was emissions from the cane trash burning before harvesting. We suggest that if the sugar mills have been promoted and encouraged the farmers to avoid the cane burning before and post harvesting it has benefited both productivity and environmental.

7.2.4 Conclusions

In this study, the life cycle environmental impact assessment was performed in order to evaluate the performance of bioethanol produced from cassava and sugarcane-molasses feedstock. The LCA software, SimaPro 8.0, was employed to analyze data gathered from the life cycle of bioethanol production in Thailand. For the environmental aspect, the GHG emissions of bioethanol were analyzed based on the LCI results by the ReCiPe method. The results indicated that the CE/avg system, ethanol conversion stage had the highest GHG impact, accounted for 58.38% of total GHGs emitted. GHG emissions of ethanol production process mainly came from coal combusted in steam boiler and the electricity consumption. In the case of biomass combination with biogas used as fuels in steam boiler has shown the environmental-friendly than coal used as fuel. For the MoE system based on sugar content allocation in sugar milling, the sugarcane cultivation stage had the highest GHG impact, accounted for 57.55% of total GHG emitted. The GHG emissions of sugarcane cultivation process mainly come from N_2O emission in N-fertilizer application and sugarcane burning before harvesting. However, if we used the cost allocation for molasses production, the result showed that this case has lower GHG emissions than the one by 30%. Compared with conventional gasoline, the GHG emissions of bioethanol were shown to be better than conventional gasoline. Furthermore, the results showed that if we included the effect from the dLUC into the bioethanol system, total GHG emissions of bioethanol production system were increased 10–37%. It is nevertheless clear that the displacement of perennial crop by annual crop is significant from a GHG perspective. In addition, in term of AP, EP, HTP, and water impact, the result showed that bioethanol system was higher impact than conventional gasoline.

For the social aspects, this study used the hybrid method, combining the process-based approach and the economic input–output analysis approach, to assess the social impacts life cycle of a bioethanol system. The result of this study showed that the bioethanol promotion has a significant impact on the social and economic development in Thailand especially in the agricultural sector in rural area. This result indicated that bioethanol production from cassava and sugarcane molasses in Thailand have the positive impact in terms of employment generation and incomes. The total employment along the supply chain of bioethanol is about 15-18 times higher than conventional gasoline. The direct employment in the cultivation stage created 70% more employment throughout the overall supply chain. However, if we considered the quality of job in cassava and sugarcane cultivating, most workers operated via daily and seasonal jobs. Normally, these employments are related to family workers and own-account workers. For the wage impacts, the result showed that the bioenergy production could increase the income distribution in agriculture workers in the rural area of the country. In addition, in term of the fatal occupational injury aspects, the result presented that bioethanol system has a higher impact than conventional gasoline. It should be improved by promoting and encourage the training and disseminating on the safety and health impacts in the workplace whole the supply chain.

7.3 Biodiesel production

7.3.1 Introduction

Biodiesel is an alternative energy from vegetable oils that is renewable sources substituting for diesel. Biodiesel is very similar to petroleum-based diesel though there are some differences. Its chemical name is an ester and a calling depends on the type of alcohol used in chemical reaction, such as methyl ester (using methyl alcohol or methanol in chemical reaction), etc. Biodiesel can be used in its pure form or could be blended with petroleum diesel at any concentration for diesel engines. In Thailand, palm oil is a renewable feedstock which has high potential as an alternative energy source for biodiesel production due to its excellent annual yield per hectare as compared to other oilseeds. In addition, biodiesel generated from palm oil is more environment-friendly compared to petroleum-based diesel in terms of carbon dioxide emission due to the carbon dioxide emitted during biodiesel combustion were those uptake from the atmosphere during the plant growth. However, there are some negative mentions concerning the sustainability of palm oil as a source of biofuel. Usually, it was reported that such extensive utilization of palm oil as biofuel would affect deforestation, which alternately would cause to possible detriment of the largest carbon sink in the world. Therefore, a cradle-to-grave analysis approach to investigate the palm biodiesel is important to sound the benefits of green energy claim. Life Cycle Assessment (LCA) is a useful tool for evaluating and quantifying the energy and environmental burden resulting associated with a product, process, or service based on cradle-to-grave approach (ISO, 2006).

This study aims to evaluate the environmental and social performance associated with biodiesel produced from palm oil in Thailand including direct land use change compared to conventional diesel, based on the life cycle approach. The life cycle inventory analysis and impact assessment were carried out based on ISO 14040 for all stages involved in the product systems, which included oil palm plantation, crude palm oil extraction, palm oil refinery, biodiesel production, and all related transport.

7.3.2 Methodology

The LCA methodology used in this work was based on ISO 14044–guidelines and requirements (ISO 2006), which consist of four steps; goal and scope definition, inventory analysis, impact assessment, and interpretation.

7.3.2.1 Goal and scope definition

The goal of this study was to assess the life cycle energy and greenhouse gases emissions associated with biodiesel from palm oil including direct land use change in Thailand. The functional unit (FU) of this study was one GJ of fuel. The scope of the biodiesel study includes the oil palm plantation, crude palm oil extraction, palm stearin production, biodiesel production, and all related transport. The system boundary of the palm oil biodiesel system is shown in Figure 7.18.

The biodiesel was compared on an equivalent energy basis with petroleum–based diesel. The environmental profiles of the petroleum–based diesel were gathered from the national life cycle inventory database of Thailand, which represents an average of production sites in Thailand.

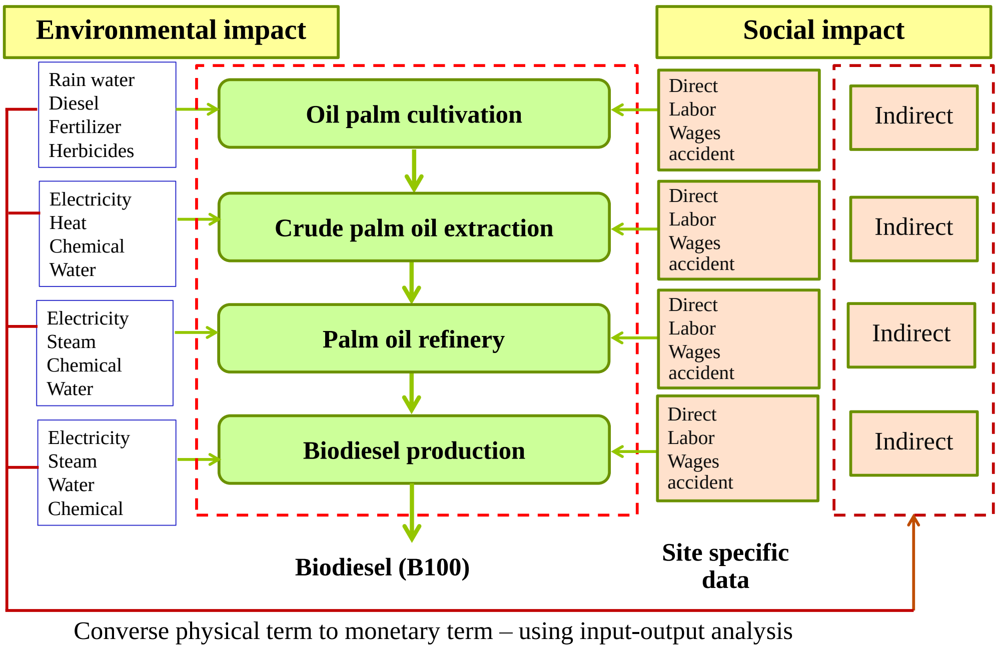


Figure 7-18. System boundary of biodiesel production from palm oil.

7.3.2.2 Data sources, assumptions, and limitations

The input–output data were collected as primary data at the actual sites in Thailand, including palm stearin production, biodiesel production, and combustion. The secondary data were used in this study as necessary and were obtained from literature reviews, the Ecoinvent databases, and calculations based on the IPCC guideline. In addition, the environmental impacts of infrastructure such as construction of the factories, equipment production and maintenance, etc., did not include in this analysis. The background data in the analysis were gathered from the national life cycle inventory (LCI) databases of Thailand (MTEC, 2011), research reports (MTEC, 2009; DEDE, 2012), and Ecoinvent databases (Ecoinvent, 2008) as described in Table 7-16.

Table 7-16. Data source of biodiesel production in this study.

Stage		**Data source**	**Sources**
Plantation	Oil palm	2nd	Papong et al. (2010)
Extraction	Crude palm oil	1st /2nd	On-site interview (2014) Kaewmai et al. (2011)
Refinery	Palm stearin	1st	On-site interview (2012)
Transportation	Palm oil	2nd	Simulation data
	Palm stearin	2nd	Simulation data
Transesterification process		2nd	Silalertsuka,and Gheewala (2012)

7.3.2.3 Data collection

7.3.2.3.1 Oil palm plantation stage

In recent year, the oil palm plantation is mainly grown in the south of Thailand, where more than 85% of the oil palm planting area is located. The oil palm plantations are concentrated in Suratthani, Krabi, and Chumporn province accounting for 65% (OAE, 2013). In addition, oil palm can be grown in other areas due to the progress in improving strain to tolerate drought well and resistance to various environments. Generally, palm trees began to yield at age 2.5-3 years after field planting and to harvest 2-3 times per month. Palm fruits are harvested only by manual labor; there is no fossil energy input to harvesting. The oil palm harvested area for the whole country in 2012 was 0.64 million hectares and fresh fruit bunches (FFB) yield was 11.24 million tonne or 17.78 tonne per hectare (OAE, 2013). In this analysis was excluded carbon dioxide from air and solar energy for the photosynthesis process. Emissions during oil palm growth from agrochemical application, it was assumed that of the total N applied 1% is assumed to be evaporated as N_2O–N (IPCC, 2006). Inventory data of oil palm cultivations were gathered from Papong et al. (2010).

7.3.2.3.2 Crude palm oil (CPO) production stage

Based on one tonne of CPO requires 6.0–6.3 tonne of FFB at its oil content is only 20% (Kaewmai et al., 2012). Palm oil is extracted from both the mesocarp of the fruit (CPO used mainly for edible oil) and the kernel (palm kernel oil (PKO), used mainly for soap manufacturing). CPO is the main product extracted from the red fruits of the oil palm, while PKO, extracted from the fruit's nut is considered to be a co-product. The CPO mills generally used the palm fiber to produce steam and electricity for their operation. The electricity consumption of the CPO mills obtained from self-production accounting for 85% and the rest from electricity grid. Inventory data for palm oil extraction were collected from the CPO mills in the southern of the country (Papong et al., 2010; Kaewmai et al., 2012). Inventory data were gathered from five CPO mills in Krabi, Surat Thani, and Chumphon and are summarized in Table 7-17. The environmental loading of the CPO production system are allocated between the CPO and PKO, based on a mass allocation approach. The scenarios were selected in this analysis divided into two case studies: the mills without biogas capture (base case) and the mill with biogas capture from wastewater treatment process (S1). The biogas recovery aims to produce electricity for replacement the national grid.

Table 7-17. Inventory data of crude palm oil extraction (before allocation).

Input			**Output**		
Item	Unit	Amount	Item	Unit	Amount
Fresh fruit brunch	tonne	6.07	CPO	tonne	1.00
Water	m^3	5.31	PKO	tonne	0.05
Electricity from grid	kWh	10.63	Palm kernel	tonne	0.20
Diesel	kg	3.85	Fibers	tonne	0.58
Kaolin	kg	12.43	Shells	tonne	0.37
Polyaluminium chloride	kg	0.23	Palm kernel meal	tonne	0.09
Sodium chloride	kg	0.44	EFB	tonne	1.21
Hydrochloric acid	kg	0.55	Decanter cake	tonne	0.16
Sodium hydroxide	kg	0.51	COD loading from wastewater	kg	43.12
			Biogas (for produce electricity)	m^3	34.14
			Electricity sale to the grid	kWh	35.5

Source: Kaewmai *et al.* (2012) and Papong et al. (2010)

7.3.2.3.3 Palm stearin production stage

Palm stearin production from crude palm oil consists of three steps: pre-treatment, refining, and fractionation. Because information on energy used in palm stearin production from CPO in Thailand has not been published, this study has gathered the inventory data from Consue et al. (2010) and verified based on sites survey in commercial plants located at central of Thailand. Based on one tonne of palm olein production requires 24 kWh of electricity and 2,100 MJ of steam. Palm olein is the main product from palm oil refining process, while palm stearin and palm fatty acid distilled (PFAD) are considered to be co-products. Every one tonne of palm olein produced generated 280 kg of palm stearin and 35 kg of PFAD.

7.3.2.3.4 Biodiesel production stage

In the transesterification process, triglycerides in palm stearin react with methanol by using sodium hydroxide or potassium hydroxide as a catalyst, a mixture of methyl esters and glycerin was produced. Methyl ester purification use water for washing process. Biofuel obtained is stored in tanks with nitrogen coverage, to prevent oxidation. Inventory data on the energy use and process chemical demand for the biodiesel production were gathered from actual sites in Thailand. Based on one tonne of biodiesel, the production requires 50 kWh of electricity and 1,100 MJ of steam. Inventory data are summarized in Table 7-18.

Table 7-18. Input and output inventory data of biodiesel production (before allocation).

Input			**Output**		
Item	Unit	Amount	Item	Unit	Amount
Palm stearin	tonne	1.02	Biodiesel	tonne	1.00
Methanol	tonne	0.10	Glycerol	tonne	0.12
Steam	MJ	1100			
Electricity	kWh	50			

Remark: Based on energy allocation: environmental burden allocated to biodiesel 92% (LHV of biodiesel = 40 MJ/kg; LHV of crude glycerin = 25 MJ/kg).

7.3.2.3.5 Transportation stage

All related transport involved in the life cycle of biodiesel production includes; FFB transport from farms to CPO mills; CPO transport from CPO mills to palm oil refining plants; and palm stearin transport from palm oil refining mills to biodiesel plants. Fuel consumption data were collected for different transportation modes by estimation and calculations. The summary of transportation stage is presented in Table 7-19.

Table 7-19. Inventory data for transportation stage in the biodiesel production system

No.	**Material**	**Place**		**Mode**	**Loading capacity (ton)**	**Distance (km)**
		From	**To**			
1	FFB	Farms	CPO mills	Truck	16	50
2	CPO	CPO mills	Palm oil refining plants	Trailer	32	700
3	Palm stearin	Palm oil refining plants	Biodiesel plants	Trailer	32	150

7.3.3 Results and discussions

7.3.3.1 GHG emissions

The life cycle GHG assessment of biodiesel covering oil palm plantation, crude palm oil extraction, palm oil refining, transportation, conversion into biodiesel, and combustion showed that the oil palm plantation stage had the highest environmental impact, as shown in Figure 7-19. The life cycle GHG emissions of biodiesel production were determined to be 41 and 29 kg CO_2 eq./GJ for the base case and S1 scenarios, respectively. For the base case scenario, the main source of GHG emissions are the methane emission from wastewater treatment process in the CPO extraction stage (36%), oil palm plantation stage (30%), and transesterification stage (15%). The main effect in oil palm plantation stage is a result of the usage of fertilizers, especially N-fertilizers during the plantation stage. Thus, attempt on reduction of the GHG impact should be made in the plantation stage where more suitable fertilizers, such as organic fertilizers, should be used. For the S1 scenario, the major source of GHG emissions are the usage of fertilizers in the oil palm plantation stage (42%), transesterification stage (21%), and CPO extraction stage (10%). Based on the functional unit defined in one GJ of fuel, it was found that the total GHG emissions of PME was lower than that of petroleum diesel.

When considering the effect from the direct land use change (dLUC) as shown in Figure 7-19, the results showed that dLUC of PME is range from (-53) to 0 kg CO_2 per GJ. The GHG emission due to the dLUC based on the land use conversion from degraded land (DL) to oil palm plantation is (-53) kg CO_2 per GJ. While, the dLUC from annual cropland (AL) and perennial cropland (PL) to oil palm plantation is (-34) and 0 kg CO_2 per GJ, respectively. The minus value indicated that the positive impact on the GHG emission due to the DL and AL conversion to oil palm plantation.

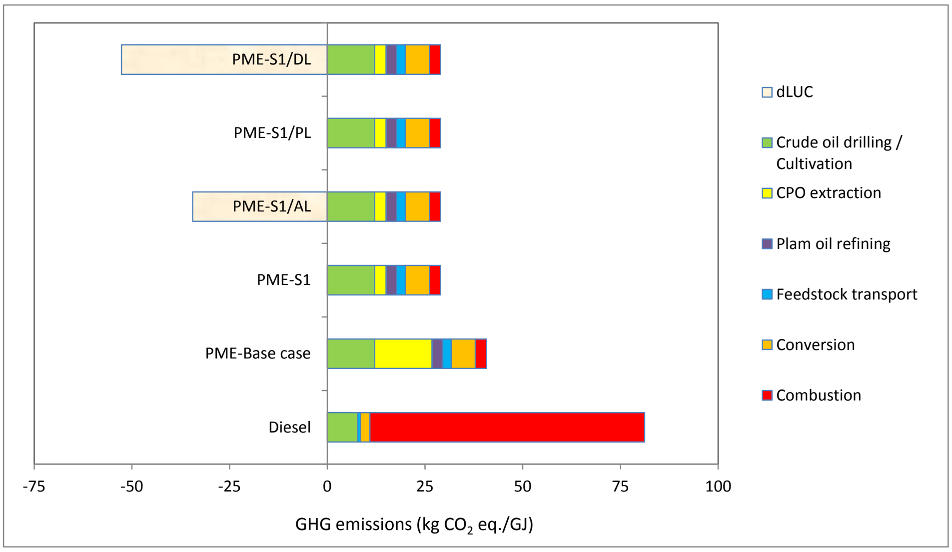


Figure 7-19. Comparison the GHG emissions of PME and diesel.

7.3.3.2 Acidification potential (AP)

Figure 7-20 shows the AP impact category of biodiesel production from palm oil of this study in comparison to petroleum diesel. The AP impact of the PME-base case accounting for 0.25 kg SO_2 eq. per GJ and the S1 case, which is the CPO mill with CH_4 capture and recovery to produce electricity for sale to the grid, of about 0.24 kg SO_2 eq. per GJ. The AP impact of the PME is mainly due to NO_x emissions from biodiesel combusted in the vehicle. The next impact is from the NO_x emission from fertilizer production. Based on the functional unit defined in one GJ of fuel, it was found that the total AP impact of PME was lower than that of petroleum diesel due to NOx emission from biodiesel combustion less than diesel.

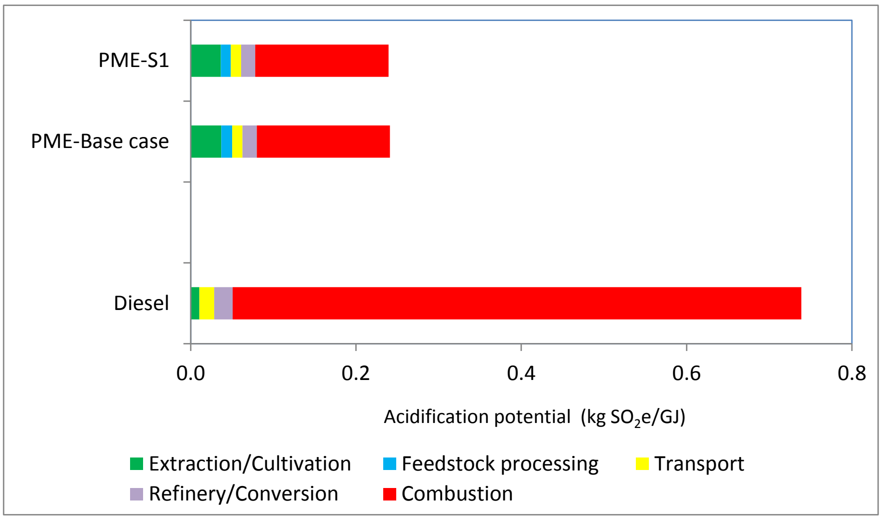


Figure 7-20. Comparison the AP impact of PME and diesel.

7.3.3.3 Socio-economic impact

7.3.3.3.1 Impact on employment

Figure 7-21 showed the direct and indirect employments generated by biodiesel production in Thailand. The results showed that the PME system generated total employment of 5.6E-03 persons per GJ. Direct employment in the oil palm plantation provides the most employment benefits contributing more than 79% of the total employment generated in the PME system. The high employment in agriculture indicates that the biodiesel promotion policy actually helps the rural area development in Thailand. In addition, in the developing countries such as Thailand, the agriculture sector is a higher labor intensity due to the cultivating systems are normally performed on the small scale farming and almost manual operation practices. The results of this study are similar to the previous study conducted by Silalertruksa et al. (2012). However, worker in the agricultural sector is mostly performed by daily and seasonal employment who are low-skilled and working under poor conditions. Generally, labors in farming are related to family workers and own-account workers.

Based on the total employment aspects, biodiesel production requires about 17 times more workers than petroleum diesel.

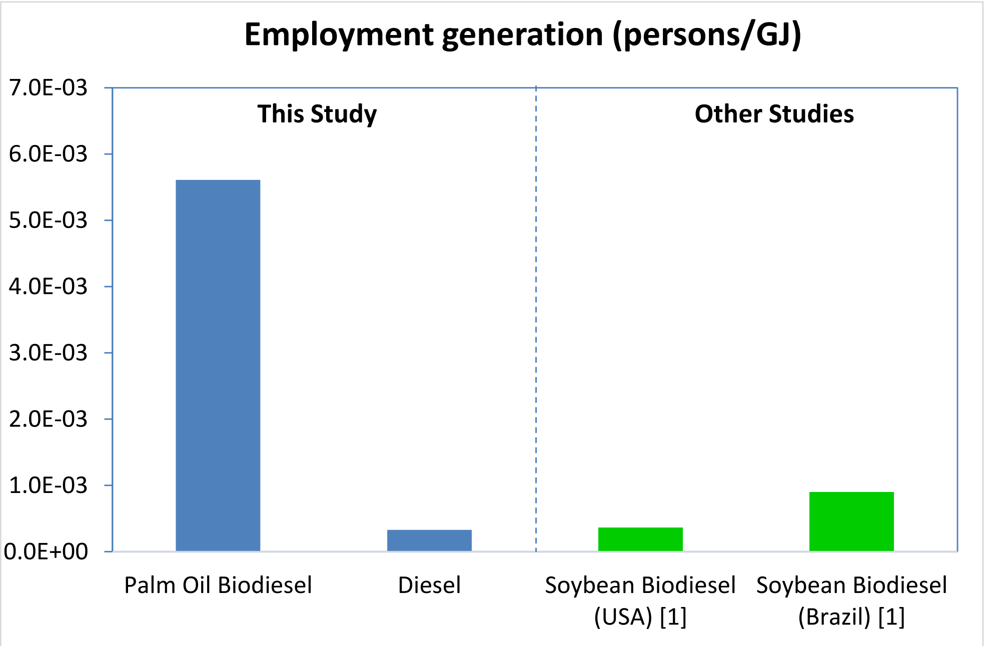


Figure 7-21. Comparison the total employment of biodiesel and diesel.

Remark: [1] International Renewable Energy Agency (IRENA) (2014)

7.3.3.3.2 Impact on wages

The direct and indirect wage impacts of biodiesel production in Thailand is presented in Figure 7-22. The overall impacts of the biodiesel production is 3.05 US$ per GJ. The wage impacts produced by biodiesel are the highest in the indirect feedstock processing stage, approximately 29% of the total wage impacts. The second impact impacts are the direct compensation of employees in the oil palm plantation (25%). When comparing the wage paid to employees, the whole biodiesel supply chain has higher wages than diesel. This aspect is due to the wage rate in the agriculture sector in Thailand being lower than other sectors, but it is very much higher labor intensity than diesel production. Based on the wages aspect, biodiesel production supply chain paid the compensation about 8.9 times more wages paid than diesel.

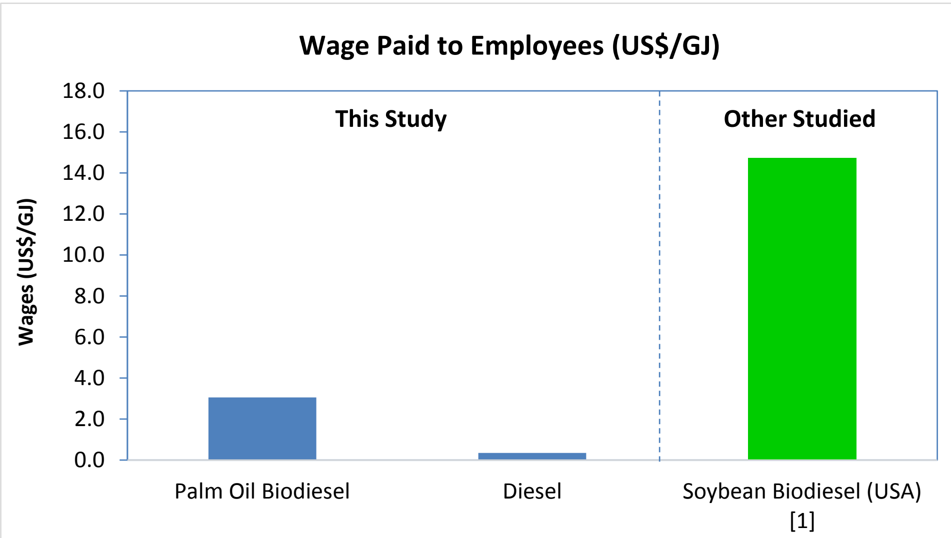


Figure 7-22. Comparison the wage paid to employees of biodiesel and diesel.

Remark: [1] LMC International (2013) - The Economic Impact of the Biodiesel Industry on the U.S. Economy

7.3.4 Conclusions

In this study, the life cycle environmental impact assessment was performed in order to evaluate the performance of biodiesel produced from palm oil. For the environmental aspect, the GHG emissions of biodiesel were analyzed based on the LCI results by the CML baseline 2000 method. The results indicated that the PME-base case, the CPO extraction stage had the highest GHG impact, accounted for 36% of total GHGs emitted. GHG emissions of CPO extraction process mainly came from CH4 emission from the wastewater treatment process. In the S1 scenario, with CH4 capture and recovery to produce electricity, has shown the environmental-friendly than base case scenario. For the PME-S1 system, the oil palm plantation stage had the highest GHG impact, accounted for 42% of total GHG emitted. The GHG emissions of oil palm cultivation process mainly come from N_2O emission in N-fertilizer application. Compared with diesel, the GHG emissions of biodiesel were shown to be better than diesel. Furthermore, the results showed that if we included the effect from the dLUC into the biodiesel system, total GHG emissions of biodiesel production system were decreased. It is clearly that the displacement of annual cropland and degraded land by perennial crop (oil palm planting) are significant reduce the GHG emissione. In addition, in term of AP impact, the result showed that biodiesel system was lower impact than conventional diesel.

For the social aspects, the result of this study showed that the biodiesel promotion has a significant impact on the social and economic development in Thailand especially in the agricultural sector in rural area. This result indicated that biodiesel production from palm oil in Thailand have the positive impact in terms of employment generation and incomes. The total employment along the supply chain of biodiesel is about 17 times higher than diesel. The direct employment in the cultivation stage created 79% more employment throughout the overall supply chain. For the wage impacts, the result showed that the biodiesel production could increase the income distribution in agriculture workers in the rural area of the country.

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Chapter 8. Conclusions

8.1 Summary

This thesis performed an environmental and social inventory database and impact assessment of occupational health. As explained in Chapter 1, the development of environmental and social inventory to support the sustainability assessment, in terms of environmental and social footprints, are important and need introducing into Thailand. In addition, to develop characterization factors for occupational health and safety in the workplace that reflect the occupational health in Thailand, these are significant to evaluate the social impact. Nevertheless, there is no available social footprint inventory to cover all economic sectors and characterization factors for occupational health and safety, reflecting the occupational health in Thailand. The development of environmental and social footprint databases in this dissertation was applied the Input-Output analysis, and the characterization factors for occupational health and safety in terms of DALY have been developed based on the five degrees of human health loss level in Thailand, with a modification of them based on the previous studied by Murray et al. (2012). The aim of this dissertation has been to investigate hotspots and to find a sustainable way of using the environmental and social footprint concept including environmental and social footprint inventory and social impact assessment.

The environmental and social intensities by economic sectors developed in this study are based on the THIO and are valuable in the national environmental and social footprint scheme since it offers the environmental and social footprint inventory (both direct and indirect) based on the national averages data. This study provides direct and an indirect environmental footprint inventory for 180 economic sectors, and a social footprint inventory for 96 economic sectors. The characterization factor in terms of DALY reflects the five degree of health loss level in Thailand.

The main findings from the development of the environmental footprint inventory database, using the THIO are as follows:

1) Top five GHG emission intensities in the primary sector are the cattle and buffalo, paddy, swine, coal and lignite, and the agricultural service sectors have a large direct GHGs share. In the secondary sectors most have large indirect GHG emission intensities in most sectors, except

the cement, tapioca milling, electricity, non-ferrous metal, natural gas separation and distribution, coconut and palm oil, rubber sheet and block rubber, and distilling blending spirits sectors. The tertiary sector has huge indirect GHG intensities in almost all sectors, except the transportation sectors (railway transport, road passenger transport, road freight transport, ocean transport, coastal and inland water transport, and air transport.

2) The majority of GHG intensities in the cement, non-ferrous metal, energy (electricity, natural gas separation, and coal and lignite), agricultural services, and transportation sectors are due to the fossil fuel combustion in the processes. While, in the coconut and palm oil, rubber sheet and block rubber, distilling blending spirits, tapioca milling, cattle and buffalo, swine, and paddy sectors come from the methane emission from wastewater treatment and rice cultivation (for paddy sector).

3) Top five SO_2 emission intensities are from ocean transport, cement, monosodium glutamate, non-ferrous metal, and basic industrial chemicals. The top five NOx intensities are the ocean transport, road freight transport, railway transport, coastal and inland water transport, and cement sectors. It should be note that the highest SO_2 and NOx intensities in these sectors are due to fossil fuel combustion such as coal, lignite, fuel oil, and diesel.

The key findings from the development of social footprint inventory study using the THIO are as follows:

1) The total employment and working-hour intensities in the agricultural and service sectors have the large direct employment and working-hour portion, The higher intensity in terms of the employment and working-hours in these sectors are the positive impacts due to the job creation in the rural areas and local communities. However, the employment in the agricultural sector has dropped continuously while employment in the service sector has increased, with female workers shifting away from the agricultural sector into the service sector. In addition, employment in agriculture is weak employment due to more than half of total employment consists of self-employed workers and unpaid family workers.

2) The wage intensity in most of the primary and service sectors have higher direct wage intensity than that of the secondary sector, because Thailand being classified as a middle-income country and having an intermediate level of production technology. An important strategy of the manufacturing sector is the use of low wages for keeping competitive advantage. Resulting in

the secondary sector having a lower share of direct wage intensity than the primary and tertiary sectors.

3) The social intensities in term of the non-fatal occupational accidents was higher in the secondary sector than in the primary and tertiary sectors. For the fatal occupational injury intensity, in the primary sector was highest in the non-metallic mining sector, whereas the secondary sector was highest in the fertilizer and pesticides, and construction sectors. In the tertiary sector was highest in the business, and transportation sectors. There are is majority due to these sector is the high-risk work activities and lack of training on the safety and prevention in the workplace accidents. However, it should be noted that the data on the fatal and non-fatal injuries in the workplace, are used in the study which published by the Social Security Office of Thailand (SSO) focusing on the incidents in formal labor of the private sector. While, the government sector and informal labors, there are no reports on the non-fatal injury and fatality cases.

4) The social intensities in this study were estimated using the social impacts throughout the entire supply chain of each industrial sectors. This study gives information for companies and consumers regarding the social issues associated with their purchases. If businesses and consumers have concerns about the social implications of their activities, they may encourage the suppliers to carry out preferable production.

5) From the case studies of inventory and impact assessment of bioplastic and biofuel, the results indicated that it is important to use inventory data and characterization factors in the social footprint assessment since social impact in each degree of human health loss level from the workplace accidents has a different degree of impact on the human health.

The major findings from the development of characterization factors of occupational workplace accident for social footprint assessment in Thailand are as follows:

1) National average DALY rate per 1000 employees in this study was 4.42, which is lower than the result of Simas et al. (2014). Because of Simas et al.s (2014) analysis included the effect from both disease and accident burdens relevant to workers, whereas this study only considered the workplace accident impacts.

2) Higher characterization factors were observed for male workers in all degrees of human health loss level due to the high risk work activities of male workers.

3) The high characterization factor and occupational health impact developed in this study show which sector the hotspots are in, and indicate that potential improvement of health and safety conditions can be achieved using policy tools. In addition, it is possible to find the

options for the mitigation of health and safety impacts into the big picture of the industrial sectors.

Furthermore, the social intensities, by economic sectors, developed in this study are based on the AIIO, that are valuable in the Asian region for social footprint scheme since it provides the social footprint inventory based on ten Asian countries' data. This study gives the direct and indirect social footprint inventory for 760 industrial sectors. The key findings from the development of the social footprint inventory database, using the AIIO, are as follows:

1) The social intensity and social footprints associated with the 76 economic sectors within 10 countries can be used to identify the key sectors and important labor issues in Asian countries. The labor intensity in terms of total employment, paid workers, vulnerable employment, non-fatal injuries, and fatal accident cases in the developing countries was higher than in developed countries, whereas wages intensity in developing countries was lower than that of developed countries.

2) The social footprints are associated with intra-country trade and inter-country trade. The social footprints associated with goods and services flow from the developing countries to developed countries; flows from China to USA, Japan, South Korea, Taiwan, and Singapore have a significant effect on the social impacts embodied in these countries. This results provides information that can assist consumers, producers, and stakeholders to identify social issues of responsibility and encourage better practices across the supply chain.

3) More advanced technologies in the developed countries implies higher wages and safety, but lower labor inputs. For example, the industrial sectors in the USA and Japan, needs less labor input with high wages and greater safety than in the developing countries such as China, Indonesia, and Philippines. On the other hand, people in developed countries normally consume more resources and produce a greater footprint than those in developing countries. The results of this study proved this hypothesis.

4) In the case of Thailand, in the primary sector, Thailand requires approximately 3–60 times more labor than in the USA to produce the same value of exports, whereas, in the secondary sector, Thailand requires approximately 2–42 times more labor than the USA to produce the same value. While, in the tertiary sector, Thailand requires approximately 5–30 times more labor than in the USA to produce the same value.

5) The outstanding feature of the social intensity is that agricultural sector in the developing countries is of a higher intensity in total employment, vulnerable employment, fatalities, and non-fatal injuries, yet low in wages. Due to the fact that the agriculture sector in the developing

countries are related to small scale farming, while in the developed countries it is usually performed on an industrial scale with mechanized farming. In addition, the agriculture works in developing countries are mostly carried out by daily laborers, seasonal laborers and temporary workers who are low-skilled and perform under poor working conditions.

6) The secondary and tertiary sectors in the developing countries showed similarities in high employment, fatal, and non-fatal injuries intensities but low intensity in income. While, in developed countries, these sectors are classified the low employment, fatal, and non-fatal injuries but high wages.

8.2 Conclusions and further studies

In conclusion, the environmental intensity expressed as tonnes pollutant per 1000 US$ and the social intensity expressed in term of labor, wages, and accident per monetary unit are significant in the following aspects. These inventory can contribute to the inventory analysis and lead to the introduction of the footprint family system of products as the carbon footprint labeling implemented in Thailand since 2009. In addition, environmental and social authorities can use this for the determination of a national plan that considers environmental and social impacts. The characterization factor for a social impact assessment can provide insights into the human health impacts in each degree of loss level. The characterization factor, in terms of DALY, developed in this study can be used to evaluate the social impact aspect at the end-point level. The environmental and social footprint inventory itself is significant, and social impact assessment using DALY can provide more helpful information to inform the social footprint and impact. The impact of social footprint at the degree of loss level on a human health vary between themselves. Social footprint assessments can be used as a tool to determine human activities as production and consumption due to the social footprint inventory, and can provide information on how much labor is used for a specific product, and can create manufactures to wise the social issues in the supply chain including production. It is expected that environmental and social footprints can have a key role for decision-making and the encouragement of environmental and social mitigation to all interested parties, towards a sustainable development. Environmental and social footprint assessments are helpful to quantify environmental and social impacts in a whole life cycle of view.

The limitations of an environmental and social footprint in this study are summarized as follows:

1) For the environmental footprint database, it should improve the economic contribution for some sector in the IO analysis. For example, the total number of cattle and buffalo in Thailand are 7.9 million heads, but economically cattle and buffalo are about 50% of the animals. The number of cattle and buffalo production for dairy and slaughtering are 1.8 million heads. It is not easy to determine economic sharing in the IO analysis due to the lack of accurate data on the cattle and buffalo classified for this kind of assessment.

2) The social footprint inventory developed by using the THIO in this thesis is the national data and some information is the aggregated data for many industrial sectors. It is expected that there is no large difference in social footprint among the aggregated industrial sectors.

3) Limitations of the social footprint inventory developed by using the AIIO is a lack of statistical data for some countries. Especially, using the official data on fatal and non-fatal injuries reported by national and international organizations that can change the results on fatal and non-fatal injuries embodied in trade. It is estimated that 50% of the labor force in developing countries work in the informal market. This study has estimated the data of non-fatal and fatal injuries from the informal market by adjusting the national statistics of each country.

4) The significant uncertainty that may labor estimates from which these footprints are calculated, especially for vulnerable employment. In this thesis it was assumed that all unpaid family workers and owned-account workers are vulnerable. However, this is not the exact data on the vulnerable employment. This observation further study the need to improve data through the specific surveys.

5) Another weak point is the gaps between the inventory and social impact in terms of DALY. DALY at sub-degree of human health loss level can be applied to the social footprint assessment reflecting human health impacts in Thailand to determine hotspots. But it should be carefully used in the social footprint impact assessment using DALY and social footprint inventory due to the fact that they have different determinations. The inventory is for each economic sector and the total number of non-fatal injuries, while DALY is for the sub-degree of human health loss level such as total permanent disability, partial permanent disability, temporary disability (>3 days leave from work), and temporary disability ($\leq$3 days leave from work).

6) This study does not address all issues for the environmental and social sustainability regarding land use footprints, biodiversity footprints, child labor and forced labor. The application of a social footprint to the case studies needs to be carefully applied because the social issues addressed in this study do not covered all social issues.

Further study is desirable to include the land use footprint, biodiversity footprint, child labor and forced labor inventory development. It is necessary to develop the characterization factors for environmental and social impact assessment in other issues. This thesis is a preliminary study of the characterization factor in term of DALY as a first step. The next work needs be performed on the human well-being and integrating the social impacts together with environmental and economic aspects. This thesis has been mainly concerned with the DALY in Thailand caused by workplace accidents. Further study on the social impacts from other countries need to be carried out for policy making in the social impact assessment. In addition, further work need be developed the environmental impact assessment modeling associated with national resources and emissions in Thailand to complete the life cycle environmental impact assessment such as biodiversity loss due to air pollutants, etc. Finally, more case studies and applications for the investigation of the environmental and social footprint database with environmental and social impact assessment are needed to refine the dataset and characterization factor.

Appendix A

Table A-1. Direct emission intensity of agricultural sector (unit: kg pollutant/1000 US$)

Sector	IO code	GHG	NOx	SO_2	PM10
Paddy	001	7,577.869	3.306	0.304	12.990
Maize	002	561.610	1.597	0.183	1.594
Other cereals	003	49.220	0.010	0.007	0.008
Cassava	004	399.677	0.492	0.156	5.536
Other root crops	005	207.909	0.013	0.010	0.012
Beans and nuts	006	710.149	1.095	0.390	11.288
Vegetable	007	306.990	0.086	0.062	0.075
Fruits	008	291.423	0.086	0.063	0.076
Sugar cane	009	979.438	9.623	0.844	14.760
Coconut	010	4.138	0.001	0.001	0.001
Oil Palm	011	397.867	0.116	0.085	0.103
Kenaf and Jute	012	281.531	0.050	0.037	0.044
Other crops for textile and matting	013	758.811	0.019	0.014	0.017
Tobacco	014	620.636	0.107	0.078	0.094
Coffee and Tea	015	752.680	0.128	0.094	0.113
Rubber	016	11.450	0.002	0.002	0.002
Other Agricultural Products	017	200.483	0.032	0.023	0.027
Cattle and Buffalo	018	13,973.545	0.045	0.037	0.040
Swine	019	1,697.152	0.058	0.016	0.149
Other Livestock	020	2,206.655	0.002	0.002	0.002
Poultry	021	647.879	0.007	0.006	0.006
Poultry Products	022	248.253	0.075	0.061	0.067
Silk Worm	023	4.710	0.001	0.001	0.001
Agricultural services	024	2,452.485	0.740	0.600	0.660
Logging	025	43.881	0.013	0.011	0.012
Charcoal and Firewood	026	30.281	0.009	0.007	0.008
Other Forestry Products	027	252.779	0.076	0.062	0.068
Ocean and Coastal Fishing	028	1,604.975	0.484	0.393	0.432
Inland Fishing	029	428.661	0.129	0.105	0.115

Table A-2. Total emission intensity of 180 industrial sectors

Sector	IO Code	GHG intensity (tonne CO2eq./1000 US$)	SO_2 intensity (kg SO2/1000 US$)	NOx intensity (kg NOx/1000 US$)	PM10 intensity (kg PM10/1000 US$)
Paddy	001	8.53	1.81	4.69	13.88
Maize	002	1.36	1.70	3.02	2.16
Other cereals	003	0.72	0.55	0.60	0.23
Cassava	004	1.10	1.47	1.68	7.08
Other root crops	005	0.82	1.24	1.01	0.35
Beans and nuts	006	1.41	1.50	2.31	13.71
Vegetable	007	1.06	1.49	1.49	0.59
Fruits	008	1.07	1.83	1.61	0.54
Sugar cane	009	1.84	2.56	11.98	16.68
Coconut	010	0.22	0.41	0.48	0.11
Oil Palm	011	1.34	2.40	2.04	0.67
Kenaf and Jute	012	0.96	0.77	0.80	0.29
Other crops for textile and matting	013	1.79	2.07	2.21	0.55
Tobacco	014	1.35	1.48	1.34	0.46
Coffee and Tea	015	1.64	2.02	1.86	0.59
Rubber	016	0.36	0.90	0.72	0.21
Other Agricultural Products	017	0.83	1.07	1.20	0.44
Cattle and Buffalo	018	14.88	0.54	0.88	1.49
Swine	019	4.03	1.78	2.45	4.41
Other Livestock	020	2.93	0.74	0.85	1.22
Poultry	021	2.13	1.42	1.85	3.13
Poultry Products	022	2.08	1.65	2.24	3.59
Silk Worm	023	0.45	0.55	0.91	0.18
Agricultural services	024	3.01	1.56	2.02	0.86
Logging	025	0.51	0.90	0.85	0.26
Charcoal and Firewood	026	0.24	0.48	0.43	0.12
Other Forestry Products	027	0.66	1.08	0.86	0.33
Ocean and Coastal Fishing	028	2.32	1.58	1.97	1.24
Inland Fishing	029	1.51	1.44	1.56	1.48
Coal and Lignite	030	3.19	1.18	9.17	0.44
Petroleum and Natural Gas	031	1.39	0.72	3.56	0.14
Iron Ore	032	1.13	3.07	2.33	0.75
Tin Ore	033	1.00	2.39	2.69	0.50
Tungsten Ore	034	1.47	3.45	3.77	0.84
Other Non-ferrous Metal Ore	035	0.86	1.45	3.70	0.44
Fluorite	036	1.92	1.99	11.50	0.61
Chemical Fertilizer Minerals	037	0.71	1.44	2.81	0.37
Salt	038	0.36	0.68	0.71	0.13
Limestone	039	0.53	1.66	1.18	0.39
Stone Quarrying	040	0.91	2.19	2.45	0.49
Other Mining and Quarrying	041	1.30	1.56	6.61	0.44
Slaughtering	042	4.73	1.50	1.75	2.54
Canning Preserving of Meat	043	3.58	2.73	2.38	1.80
Dairy Products	044	2.82	3.13	3.41	1.50

Canning of Fruits and Vegetables	045	1.63	3.23	2.66	1.06
Canning Preserving of Fish	046	1.78	2.55	2.31	1.22
Coconut and Palm Oil	047	4.82	3.97	4.38	0.69
Animal oil, animal fat, vegetable oil and by-products	048	1.56	1.96	2.50	10.57
Rice Milling	049	7.01	2.43	5.14	11.40
Tapioca Milling	050	9.88	2.90	3.03	5.48
Drying and Grinding of Maize	051	1.15	1.95	3.07	1.68
Flour and Other Grain Milling	052	3.91	1.81	2.57	4.29
Bakery Products	053	2.29	2.88	3.17	2.21
Noodles and Similar Products	054	2.73	3.14	2.96	3.05
Sugar	055	1.60	7.62	12.15	6.23
Confectionery	056	1.87	3.72	4.52	2.64
Ice	057	2.95	4.97	5.92	0.70
Monosodium Glutamate	058	6.49	17.44	9.22	5.85
Coffee and Tea Processing	059	1.01	3.16	2.05	0.78
Other Food Products	060	1.46	2.42	2.24	1.96
Animal Feed	061	1.66	2.12	2.61	5.42
Distilling Blending Spirits	062	2.67	2.83	2.84	1.41
Breweries	063	0.81	2.02	1.55	0.58
Soft Drinks	064	1.26	4.06	3.79	1.56
Tobacco Processing	065	1.19	3.23	1.87	0.75
Tobacco Products	066	0.28	0.73	0.45	0.17
Spinning	067	1.66	2.81	2.79	0.54
Weaving	068	1.83	4.26	3.48	0.78
Textile Bleaching and Finishing	069	3.01	11.39	5.29	2.59
Made-up Textile Goods	070	1.58	5.74	2.98	1.14
Knitting	071	1.17	2.55	2.15	0.52
Wearing Apparels Except Footware	072	1.46	3.32	2.77	0.63
Carpets and Rugs	073	1.48	4.50	2.54	0.94
Jute mill products	074	0.88	1.94	1.54	0.43
Tanneries and leather finishing	075	2.88	2.38	2.09	1.62
Leather products	076	1.36	2.84	2.15	0.86
Footwear, except of rubber	077	1.31	2.61	2.11	0.69
Saw mills	078	0.94	1.88	2.24	0.41
wood and cork products	079	0.91	1.90	2.24	0.42
Wooden furniture and fixtures	080	0.98	2.07	2.03	0.48
Pulp, paper and paperboard	081	3.38	8.34	4.26	1.95
Paper and paperboard products	082	2.62	6.94	3.72	1.62
Printing and publishing	083	2.03	5.60	3.27	1.33
Basic industrial chemicals	084	3.16	11.48	8.00	2.65
Fertilizer and pesticides	085	2.38	6.62	5.16	1.56
Petrochemical products	086	1.17	1.64	2.31	0.33
Paints	087	1.82	3.93	4.05	0.97
Drugs and medicines	088	1.45	3.62	3.09	1.03
Soap and cleaning preparations	089	2.08	6.38	4.83	1.67
Cosmetic	090	1.74	4.80	4.03	1.56
Matches	091	1.61	5.66	4.02	1.27
Other chemical products	092	1.98	5.92	4.60	1.71

Petroleum refineries	093	1.18	0.82	2.99	0.16
Other petroleum products	094	1.38	10.62	2.47	2.21
Rubber sheet and block rubber	095	2.08	2.18	1.46	0.48
Tyres and Tubes	096	1.69	4.20	2.93	0.83
Other Rubber Products	097	1.39	2.74	2.22	0.57
Plastic Wares	098	1.55	3.14	3.15	0.61
Caramic and Earthen Wares	099	2.83	4.98	6.03	1.20
Glass and Glass Products	100	2.19	4.19	5.17	0.94
Structural Clay Products	101	3.17	4.80	6.86	1.42
Cement	102	16.08	29.29	26.77	8.07
Concrete and Cement Products	103	4.51	8.85	7.99	2.31
Other Non-metallic Products	104	4.70	8.21	9.03	2.15
Iron and Steel	105	3.13	9.19	6.45	1.65
Secondary Steel Products	106	2.33	6.54	4.79	1.23
Non-ferrous Metal	107	5.27	17.04	11.46	5.37
Cutlery and Hand Tools	108	2.12	6.11	4.55	1.60
Furniture and Fixtures Metal	109	1.78	4.70	3.72	1.05
Structural Metal Products	110	1.98	5.55	4.25	1.33
Other Fabricated Metal Products	111	2.10	5.65	4.43	1.30
Engines and Turbines	112	1.56	5.08	3.30	1.10
Agricultural Machinery	113	1.52	3.75	3.16	0.76
Wood and Metal Working Machinery	114	2.08	5.20	4.38	1.35
Special Industrial Machinery	115	1.78	5.71	3.85	1.30
Office and Household Machinery	116	1.26	3.34	2.68	0.74
Electrical Industrial Machinery	117	1.60	4.16	3.38	1.04
Radio and Television	118	1.24	3.09	2.68	0.75
Household Electrical Appliances	119	1.71	4.66	3.64	1.09
Insulated Wire and Cable	120	2.71	8.25	5.85	2.45
Electric Accumulator & Battery	121	2.74	7.86	5.76	2.16
Other Electrical Aparatuses & Supplies	122	1.58	4.38	3.41	1.04
Ship Building	123	1.32	3.08	2.80	0.66
Railway Equipment	124	1.87	7.02	4.10	1.55
Motor Vehicle	125	1.57	4.27	3.29	0.94
Motorcycle, Bicycle & Other Carriages	126	1.78	5.23	3.76	1.19
Repairing of Motor Vehicle	127	1.44	4.07	2.98	0.89
Aircraft	128	1.27	4.83	2.69	1.01
Scientific Equipments	129	1.26	3.27	2.73	0.76
Photographic & Optical Goods	130	0.95	2.28	2.10	0.49
Watches and Clocks	131	1.36	3.65	3.05	0.94
Jewelry & Related Articles	132	2.98	9.23	6.66	2.83
Recreational and Athletic Equipment	133	1.68	3.39	3.03	0.90
Other Manufacturing Goods	134	1.89	4.66	3.44	1.29
Electricity	135	7.14	10.12	13.90	1.11
Pipeline and gas distribution	136	2.60	0.77	2.99	0.22
Water Supply System	137	1.40	2.45	2.80	0.37
Residential Building Construction	138	3.23	6.31	7.20	1.63

Non-Residential Building Construction	139	3.49	6.72	7.59	1.71
Public Works for Agriculture & Forestry	140	2.97	5.91	5.98	1.51
Non-Agricultural Public Works	141	2.88	5.38	8.72	1.38
Construction of Electric Plant	142	2.88	6.27	8.30	1.72
Construction of Communication Facilities	143	1.75	4.51	4.13	1.18
Other Constructions	144	2.24	4.37	5.09	1.12
Wholesale Trade	145	0.38	0.54	0.87	0.12
Retail Trade	146	0.42	0.64	0.84	0.14
Restaurant and Drinking Place	147	1.72	1.66	1.95	1.18
Hotel and Lodging Place	148	2.10	3.22	3.98	0.61
Railways	149	2.72	2.14	29.71	1.16
Route & Non Route of Road Passenger Trans.	150	5.23	2.93	17.15	1.30
Road Freight Transport	151	6.15	2.92	42.28	1.32
Land Transport Supporting Services	152	0.39	0.62	1.28	0.14
Ocean Transport	153	4.40	45.60	90.27	7.16
Coastal & Inland Water Transport	154	3.40	2.11	27.44	3.12
Water Transport Services	155	1.12	1.22	6.04	0.75
Air Transports	156	3.17	1.96	11.93	0.23
Other Services	157	1.17	1.25	5.24	0.36
Silo and Warehouse	158	1.67	2.44	3.51	0.36
Post and Telecommunication	159	0.64	0.92	1.67	0.19
Banking Services	160	0.53	1.04	1.00	0.23
Life Insurnce Service	161	0.37	0.54	0.88	0.12
Other Insurance Service	162	0.37	0.56	0.82	0.14
Real-estate	163	0.35	0.54	0.70	0.09
Business Service	164	0.94	1.92	1.82	0.44
Public Administration	165	0.00	-	-	-
Sanitary and Similar Services	166	0.61	1.11	1.28	0.25
Education	167	0.62	1.03	1.10	0.29
Research	168	0.71	1.48	1.45	0.35
Hospital	169	1.14	2.26	2.29	0.61
Business and Labor Associations	170	0.72	1.09	1.57	0.25
Other Community Services	171	0.67	0.72	1.12	0.39
Motion Picture Production	172	1.33	2.94	2.68	0.76
Movie Theater	173	1.14	2.27	2.31	0.53
Radio, Television and Related Services	174	0.86	1.57	1.80	0.33
Livrary and Museum	175	0.61	1.23	1.05	0.31
Amusement and Recreation	176	0.61	0.99	1.11	0.29
Repair, Not Elsewhere Classified	177	1.22	2.92	2.59	0.68
Personal Services	178	1.13	2.30	2.36	0.57
Unclassified	180	2.25	3.86	4.05	1.32
AVG		**2.10**	**3.76**	**4.61**	**1.61**
SD		**2.06**	**4.61**	**8.20**	**2.25**

Appendix B

Table B-1. Definition of economic sectors for the new aggregated IO table (96x96 sectors) compare to the conventional IO table (180x180 sectors)

Code	Conventional Thai IO table (180x180 sectors)	New code	Aggregated sectors (96x96 sectors)
001	Paddy	001	Paddy
002	Maize	002	Maize and cereals
003	Other cereals		
004	Cassava	003	Cassava
005	Other root crops	004	Beans, vegetables, and other root crops
006	Beans and nuts		
007	Vegetables		
008	Fruits	005	Fruits and coconut
010	Coconut		
009	Sugarcane	006	Sugarcane
011	Oil palm	007	Oil palm
012	Kenaf and jute	008	Textile crops
013	Crops for textile and matting		
014	Tobacco	009	Tobacco
015	Coffee and tea	010	Coffee and tea
016	Rubber	011	Rubber
017	Other agricultural products	012	Other agricultural products
018	Cattle and buffalo	013	Livestock
019	Swine		
020	Other livestock		
021	Poultry		
022	Poultry products		
023	Silk worm		
024	Agricultural services	014	Agricultural services
025	Logging	015	Forestry
026	Charcoal and firewood		
027	Other forestry products		
028	Ocean and coastal fishing	016	Fishery
029	Inland fishing		
030	Coal and lignite	017	Coal and lignite
031	Petroleum and natural gas	018	Petroleum and natural gas
032	Iron ore	019	Metal ore mining
033	Tin ore		
034	Tungsten ore		
035	Other non-ferrous metal ore		
036	Fluorite	020	Non-metal ore mining
037	Chemical fertilizer minerals		
038	Salt evaporation		
039	Limestone		
040	Stone quarrying		
041	Other mining and quarrying		
042	Slaughtering	021	Slaughtering, meat canned, and dairy products
043	Canning preserving of meat		
044	Dairy products		
045	Canning of fruits and vegetables	022	Canning of fruits and vegetables
046	Canning preserving of fish	023	Canning preserving of fish
047	Coconut and palm oil	024	Coconut and palm oil
048	Other vegetable and animal oils	025	Other vegetable and animal oils
049	Rice milling	026	Rice milling and grinding of maize
051	Drying and grinding of maize		
050	Tapioca milling	027	Tapioca milling
052	Flour and other grain milling	028	Flour and other grain milling
053	Bakery products	029	Other food products
054	Noodles and similar products		
056	Confectionery		
057	Ice		

058	Monosodium glutamate		
060	Other food products		
055	Sugar	030	Sugar
059	Coffee and tea processing	031	Coffee and tea processing
061	Animal feed	032	Animal feed
062	Distilling blending spirits	033	Distilling blending spirits
063	Breweries	034	Breweries
064	Soft drinks	035	Soft drinks
065	Tobacco processing	036	Tobacco processing and products
066	Tobacco products		
067	Spinning	037	Spinning
068	Weaving	038	Textile weaving, bleaching and finishing
069	Textile bleaching and finishing		
070	Made-up textile goods	039	Made-up textile goods and knitting
071	Knitting		
072	Wearing apparels except footwear	040	Wearing apparels except footwear
073	Carpets and rugs	041	Carpets, rugs, cordage rope, and twine products
074	Cordage rope and twine products		
075	Tanneries leather finishing	042	Leather products and footwear
076	Leather products		
077	Footwear except rubber		
078	Saws mills	043	Saws mills
079	Wood and cork products	044	Wood and cork products
080	Furniture and fixtures wood	045	Furniture and fixtures wood
081	Pulp paper and paperboard	046	Pulp and paper products
082	Paper products		
083	Printing and publishing	047	Printing and publishing
084	Basic industrial chemicals	048	Basic industrial chemicals
085	Fertilizer and pesticides	049	Fertilizer and pesticides
086	Synthetic resins and plastics	050	Synthetic resins and plastics
087	Paints varnishes and lacquers	051	Paints varnishes, cleaning products, cosmetics and other chemical products
089	Soap and cleaning preparations		
090	Cosmetics		
091	Matches		
092	Other chemical products		
088	Drugs and medicines	052	Drugs and medicines
093	Petroleum refineries	053	Petroleum refineries products
094	Other petroleum products		
095	Rubber sheets and block rubber	054	Rubber sheets, block rubber, tires, and tubes
096	Tires and tubes		
097	Other rubber products	055	Other rubber products
098	Plastic wares	056	Plastic wares
099	Ceramics and earthen wares	057	Ceramics and clay products
101	Structural clay products		
104	Other mon-metallic products		
100	Glass and glass products	058	Glass and glass products
102	Cement	059	Cement and concrete products
103	Concrete and Cement Products		
105	Iron and steel	060	Iron and steel products
106	Secondary steel products		
107	Non-ferrous metal	061	Non-ferrous metal
108	Cutlery and hand tools	062	Fabricated metal products
109	Furniture and fixtures metal		
110	Structural metal products		
111	Other fabricated metal products		
112	Engines and turbines	063	Engines and turbines
113	Agricultural machinery	064	Agricultural machinery
114	Wood and metal working machinery	065	Wood and metal working machinery
115	Special industrial machinery	066	Special industrial machinery
116	Office and household machinery	067	Office and household machinery
117	Electrical industrial machinery	068	Electrical industrial machinery
118	Radio and television	069	Radio and television
119	Household electrical appliances	070	Household electrical appliances
120	Insulated wire and cable	071	

121	Electric accumulator and battery		Wire, cable, battery, and other electrical apparatuses
122	Other electrical apparatuses and supplies		
123	Ship building	072	Ship building
125	Motor vehicle	073	Motor vehicle
126	Motorcycle, bicycle and other carriages	074	Motorcycle, bicycle and other carriages
124	Railway equipment	075	Railway equipment, repairing of motor vehicle, and aircraft
127	Repairing of motor vehicle		
128	Aircraft		
129	Scientific equipment	076	Precision products
130	Photographic and optical goods		
131	Watches and clocks		
132	Jewelry and related articles	077	Jewelry and related articles
133	Recreational and athletic equipment	078	Other manufacturing goods
134	Other manufacturing goods		
135	Electricity	079	Electricity
136	Pipeline	080	Pipeline
137	Water supply system	081	Water supply system
138	Residential building construction	082	Construction
139	Non-residential building construction		
140	Public works for agriculture and forestry		
141	Non-agricultural public works		
142	Construction of electric plant		
143	Construction of communication facilities		
144	Other constructions		
145	Wholesale trade	083	Wholesale and retail trade
146	Retail trade		
147	Restaurant and drinking place	084	Restaurant and drinking place
148	Hotel and lodging place	085	Hotel and lodging place
149	Railways	086	Transportation
150	Route and non-route of road passenger trans.		
151	Road freight transport		
152	Land transport supporting services		
153	Ocean transport		
154	Coastal and inland water transport		
155	Water transport services		
156	Air transports		
157	Other services		
158	Silo and warehouse		
159	Post and telecommunication	087	Post and telecommunication
160	Banking services	088	Financial services
161	Life insurance service		
162	Other insurance service		
163	Real-estate	089	Real-estate
164	Business service	090	Business service
165	Public administration	091	Public administration
166	Sanitary and similar services	092	Sanitary and similar services
167	Education	093	Education and research
168	Research		
169	Hospital	094	Hospital
170	Business and labor associations	095	Other services
171	Other community services		
172	Motion picture production		
173	Movie theater		
174	Radio, television and related services		
175	Library and museum		
176	Amusement and recreation		
177	Repair, Not elsewhere classified		
178	Personal services		
180	Unclassified	096	Unclassified

Table B-2. Total social intensity of Thailand for 96 industrial sectors based on the THIO

Sector	IO code	Employment intensity (person/1000 US$)	Wages intensity (US$/US$)	Worked-hour intensity (hours/1000 US$)	Fatal intensity (cases/1000 US$)	Non-fatal intensity (cases/1000 US$)
Paddy	001	0.748	0.261	1,192	3.42E-06	1.06E-02
Maize & other grain	002	0.742	0.497	1,246	5.74E-06	1.05E-02
Cassava	003	0.858	0.411	1,240	6.28E-06	1.18E-02
Bean & vegetables	004	0.791	0.217	976	5.71E-06	1.11E-02
Fruits	005	0.723	0.170	857	4.62E-06	1.01E-02
Sugarcane	006	0.774	0.390	1,146	5.76E-06	1.07E-02
Oil Palm	007	0.727	0.229	924	1.17E-05	1.03E-02
Textile crops	008	0.689	0.219	865	6.43E-06	1.11E-02
Tobacco	009	0.737	0.204	909	6.47E-06	1.20E-02
Coffee and Tea	010	0.728	0.269	926	9.73E-06	1.01E-02
Rubber	011	0.649	0.194	833	2.84E-06	1.05E-02
Other Agricultural Products	012	0.697	0.238	914	6.17E-06	1.13E-02
Livestock & poultry	013	0.248	0.214	461	1.60E-05	5.08E-03
Agricultural service	014	0.091	0.163	178	1.61E-05	1.40E-03
Forestry	015	0.413	0.470	1,077	2.82E-05	6.14E-03
Fishery	016	0.173	0.183	324	4.17E-06	2.50E-03
Lignite mining	017	0.024	0.213	57	4.42E-06	4.30E-04
Crude petroleum & natural gas	018	0.024	0.221	52	3.85E-06	3.45E-04
Metallic mining	019	0.038	0.223	81	3.81E-06	3.96E-04
Non-metallic ore & quarrying	020	0.065	0.220	135	6.68E-05	1.46E-03
Slaughtering, meat & dairy products	021	0.175	0.229	327	1.63E-05	3.43E-03
Canning of Fruits and Vegetables	022	0.332	0.200	452	1.06E-05	5.10E-03
Canning Preserving of Fish	023	0.122	0.165	243	7.13E-06	2.16E-03
Coconut and Palm Oil	024	0.476	0.216	632	1.26E-05	7.00E-03
Animal oil/fat & other vegetable oil	025	0.056	0.089	105	5.93E-06	1.10E-03
Rice Milling & Grinding of Maize	026	0.602	0.281	975	1.70E-05	8.77E-03
Tapioca Milling	027	0.569	0.352	851	1.85E-05	8.09E-03
Flour and Other Grain Milling	028	0.278	0.184	457	1.47E-05	4.16E-03
Other Food Products	029	0.165	0.212	282	1.29E-05	2.95E-03
Sugar	030	0.275	0.268	433	7.70E-06	3.78E-03
Coffee and Tea Processing	031	0.193	0.281	336	1.92E-05	3.89E-03
Animal Feed	032	0.195	0.181	338	6.70E-06	3.01E-03
Distilling Blending Spirits	033	0.103	0.126	166	6.49E-06	1.54E-03
Breweries	034	0.026	0.105	50	3.43E-06	5.23E-04
Soft Drinks	035	0.084	0.175	161	1.18E-05	1.48E-03
Tobacco Processing & products	036	0.047	0.099	71	1.11E-06	7.23E-04
Spinning & Weaving	037	0.082	0.177	167	1.05E-05	1.93E-03
Dyeing	038	0.079	0.229	162	7.76E-06	1.80E-03
Knitting	039	0.084	0.213	172	7.96E-06	1.91E-03
Wearing Apparels Except Footwear	040	0.107	0.239	286	1.44E-05	1.68E-03

Table B-2. (Continue)

Sector	IO code	Employment intensity (person/1000 US$)	Wages intensity (US$/US$)	Worked-hour intensity (hours/1000 US$)	Fatal intensity (cases/1000 US$)	Non-fatal intensity (cases/1000 US$)
Other made-up textile products	041	0.240	0.225	477	1.55E-05	5.30E-03
Leather & leather products	042	0.079	0.227	157	7.99E-06	1.65E-03
Saw mills	043	0.134	0.290	471	3.68E-05	3.45E-03
wood and cork products	044	0.296	0.306	789	1.35E-05	7.14E-03
Wooden furniture and fixtures	045	0.068	0.264	418	1.10E-05	2.20E-03
Pulp, paper and paperboard products	046	0.066	0.167	143	9.31E-06	1.49E-03
Printing and publishing	047	0.115	0.182	241	2.28E-05	2.23E-03
Basic industrial chemicals	048	0.047	0.137	95	4.81E-06	9.54E-04
Fertilizer and pesticides	049	0.078	0.120	160	4.68E-05	1.72E-03
Petrochemical products	050	0.021	0.191	46	2.72E-06	3.94E-04
Other chemical products	051	0.060	0.181	118	7.04E-06	1.21E-03
Drugs and medicines	052	0.084	0.189	157	4.40E-06	1.29E-03
Petroleum refineries & its products	053	0.003	0.030	5	2.62E-07	3.06E-05
Rubber, tires & tubes	054	0.336	0.196	460	7.31E-06	5.27E-03
Other Rubber Products	055	0.136	0.243	230	1.28E-05	4.14E-03
Plastic products	056	0.087	0.185	179	1.63E-05	2.79E-03
Ceramics & other Non-metallic Products	057	0.099	0.221	207	1.99E-05	1.81E-03
Glass and Glass Products	058	0.047	0.189	100	9.16E-06	1.20E-03
Cement & cement products	059	0.053	0.191	109	3.76E-05	1.57E-03
Iron & steel	060	0.026	0.162	54	1.31E-05	1.62E-03
Non-ferrous Metal	061	0.037	0.139	76	1.05E-05	1.48E-03
Metal products	062	0.068	0.134	142	2.04E-05	5.77E-03
Boiler, engines & turbines	063	0.063	0.173	131	6.00E-06	4.19E-03
Agricultural machinery	064	0.118	0.259	243	2.01E-05	6.75E-03
Metal working machinery	065	0.082	0.148	175	1.48E-05	4.03E-03
Special Industrial Machinery	066	0.026	0.142	56	4.20E-06	8.85E-04
Electrical Industrial Machinery	067	0.026	0.104	58	3.98E-06	7.38E-04
Household Machinery	068	0.061	0.117	129	1.04E-05	3.18E-03
Radio and Television	069	0.028	0.055	57	3.65E-06	3.59E-04
Home appliances	070	0.045	0.124	96	7.71E-06	1.78E-03
Battery, Cable & lighting	071	0.026	0.116	55	4.15E-06	8.86E-04
Ship Building	072	0.037	0.256	84	5.13E-06	1.38E-03
Motor Vehicle	073	0.031	0.100	62	5.30E-06	9.72E-04
Motorcycle, Bicycle & Other Carriages	074	0.057	0.151	118	6.77E-06	1.24E-03
Other transport equipment	075	0.090	0.166	179	3.01E-06	6.60E-04
Precision machines	076	0.033	0.159	157	2.90E-06	4.72E-04
Jewelry & Related Articles	077	0.031	0.138	67	3.72E-06	4.56E-04
Other Manufacturing Goods	078	0.135	0.183	183	6.81E-06	1.89E-03
Electricity generation	079	0.019	0.256	38	5.74E-06	2.74E-04
Pipeline and gas separation	080	0.023	0.204	49	4.14E-06	3.32E-04
Water Supply	081	0.035	0.324	67	2.22E-06	9.67E-04

Table B-2. (Continue)

Sector	IO code	Employment intensity (person/1000 US$)	Wages intensity (US$/US$)	Worked-hour intensity (hours/1000 US$)	Fatal intensity (cases/1000 US$)	Non-fatal intensity (cases/1000 US$)
Construction	082	0.155	0.202	376	5.83E-05	6.92E-03
Wholesale & Retail Trade	083	0.112	0.248	262	1.36E-05	1.93E-03
Restaurant and Drinking Place	084	0.211	0.213	493	9.96E-06	3.29E-03
Hotel and Lodging Place	085	0.245	0.269	494	1.07E-05	3.83E-03
Transportation	086	0.063	0.223	171	2.57E-05	9.61E-04
Post and Telecommunication	087	0.038	0.275	78	5.36E-06	5.33E-04
Finance & insurance	088	0.062	0.308	107	6.30E-06	4.68E-04
Real-estate	089	0.109	0.122	123	3.07E-06	1.30E-03
Business Service	090	0.161	0.290	345	2.77E-05	2.24E-03
Public Administration	091	0.137	0.916	266	6.69E-07	1.99E-03
Sanitary & Similar Services	092	0.175	0.583	387	3.07E-05	2.31E-03
Education & research	093	0.146	0.694	267	1.10E-05	7.83E-04
Hospital	094	0.175	0.384	365	9.19E-06	2.76E-03
Other services	095	0.158	0.291	363	2.73E-05	2.14E-03
Unclassified	096	0.120	0.190	220	9.63E-06	2.03E-03
AVG		**0.200**	**0.227**	**336**	**1.18E-05**	**3.46E-03**
SD		**0.233**	**0.123**	**325**	**1.13E-05**	**3.38E-03**

Appendix C

Table C-1. Definition of economic sectors based on the 2005 Asian International input–output table (76 sectors).

IO Code	Economic Sector
Primary sector	
1	Paddy
2	Other grain
3	Food crops
4	Non-food crops
5	Livestock and poultry
6	Forestry
7	Fishery
8	Crude petroleum and natural gas
9	Iron ore
10	Other metallic ore
11	Non-metallic ore and quarrying
Secondary sector	
12	Milled grain and flour
13	Fish products
14	Slaughtering, meat products and dairy products
15	Other food products
16	Beverage
17	Tobacco
18	Spinning
19	Weaving and dyeing
20	Knitting
21	Wearing apparel
22	Other made-up textile products
23	Leather and leather products
24	Timber
25	Wooden furniture
26	Other wooden products
27	Pulp and paper
28	Printing and publishing
29	Synthetic resins and fiber
30	Basic industrial chemicals
31	Chemical fertilizers and pesticides
32	Drugs and medicine
33	Other chemical products
34	Refined petroleum and its products
35	Plastic products
36	Tires and tubes
37	Other rubber products
38	Cement and cement products
39	Glass and glass products
40	Other non-metallic mineral products
41	Iron and steel
42	Non-ferrous metal
43	Metal products
44	Boilers, Engines and turbines
45	General machinery
46	Metal working machinery
47	Specialized machinery
48	Heavy Electrical equipment

Table C-1. (Continue)

IO Code	Economic Sector
49	Television sets, radios, audios and communication equipment
50	Electronic computing equipment
51	Semiconductors and integrated circuits
52	Other electronics and electronic products
53	Household electrical equipment
54	Lighting fixtures, batteries, wiring and others
55	Motor vehicles
56	Motor cycles
57	Shipbuilding
58	Other transport equipment
59	Precision machines
60	Other manufacturing products
61	Electricity and gas
62	Water supply
63	Building construction
64	Other construction
Tertiary sector	
65	Wholesale and retail trade
66	Transportation
67	Telephone and telecommunication
68	Finance and insurance
69	Real estate
70	Education and research
71	Medical and health service
72	Restaurants
73	Hotel
74	Other services
75	Public administration
76	Unclassified

Table C-2. Employment intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	1.430	1.022	1.456	-	0.818	0.881	0.073	0.082	0.146	-
Other grain	1.142	0.097	2.206	-	0.792	0.906	0.152	0.159	0.023	0.016
Food crops	1.084	0.150	0.426	-	0.821	0.856	0.089	0.066	0.056	0.013
Non-food crops	1.175	0.228	0.384	0.135	0.698	0.842	0.068	0.024	0.053	0.016
Livestock and poultry	0.525	0.063	0.215	0.133	0.291	1.013	0.078	0.067	0.044	0.018
Forestry	0.240	0.034	1.110	-	0.419	0.859	0.032	0.059	0.014	0.013
Fishery	0.268	0.107	0.437	0.111	0.192	0.928	0.043	0.035	0.031	0.015
Crude petroleum and natural gas	0.008	0.013	0.011	-	0.026	0.109	0.008	0.007	0.011	0.008
Iron ore	0.399	0.077	-	-	0.207	0.176	0.028	0.016	0.011	0.010
Other metallic ore	0.052	0.080	0.116	-	0.188	0.163	0.067	0.030	0.013	0.009
Non-metallic ore and quarrying	0.086	0.065	0.099	-	0.048	0.172	0.012	0.016	0.015	0.010
Milled grain and flour	0.971	0.460	0.652	0.285	0.618	0.511	0.062	0.095	0.094	0.014
Fish products	0.216	0.094	0.221	0.088	0.173	0.525	0.064	0.063	0.036	0.074
Slaughtering, meat products and dairy products	0.367	0.118	0.119	0.078	0.206	0.619	0.052	0.053	0.036	0.018
Other food products	0.532	0.129	0.285	0.121	0.328	0.467	0.060	0.078	0.039	0.016
Beverage	0.484	0.088	0.168	0.046	0.078	0.399	0.028	0.021	0.017	0.019
Tobacco	0.186	0.089	0.071	0.106	0.047	0.169	0.006	0.010	0.009	0.007
Spinning	0.183	0.156	0.392	0.101	0.164	0.317	0.050	0.072	0.079	0.025
Weaving and dyeing	0.231	0.074	0.352	0.101	0.090	0.352	0.038	0.043	0.031	0.024
Knitting	0.141	0.104	0.159	0.102	0.122	0.268	0.035	0.050	0.041	0.020
Wearing apparel	0.353	0.150	0.330	0.093	0.128	0.243	0.063	0.046	0.045	0.026
Other made-up textile products	0.203	0.097	0.396	0.071	0.173	0.307	0.052	0.039	0.036	0.021
Leather and leather products	0.359	0.083	0.636	0.107	0.105	0.378	0.117	0.048	0.035	0.026
Timber	0.688	0.068	0.211	0.085	0.170	0.885	0.144	0.055	0.035	0.015
Wooden furniture	0.707	0.072	0.314	0.094	0.098	0.256	0.112	0.047	0.033	0.024
Other wooden products	0.357	0.090	0.499	0.097	0.241	0.243	0.091	0.052	0.029	0.018
Pulp and paper	0.119	0.086	0.279	0.052	0.093	0.238	0.043	0.029	0.022	0.013
Printing and publishing	0.248	0.087	0.194	0.036	0.137	0.176	0.035	0.027	0.017	0.012
Synthetic resins and fiber	0.044	0.027	0.100	0.030	0.070	0.241	0.030	0.023	0.017	0.012
Basic industrial chemicals	0.047	0.043	0.080	0.034	0.040	0.155	0.022	0.021	0.018	0.011
Chemical fertilizers and pesticides	0.037	0.050	0.077	0.029	0.112	0.177	0.038	0.033	0.019	0.010
Drugs and medicine	0.265	0.075	0.159	0.026	0.104	0.264	0.030	0.023	0.013	0.008
Other chemical products	0.198	0.056	0.148	0.031	0.086	0.164	0.029	0.025	0.017	0.012
Refined petroleum and its products	0.010	0.032	0.017	0.042	0.010	0.193	0.011	0.011	0.007	0.009
Plastic products	0.124	0.074	0.096	0.044	0.117	0.191	0.032	0.024	0.021	0.014
Tires and tubes	0.210	0.108	0.139	0.051	0.370	0.195	0.021	0.049	0.045	0.020
Other rubber products	0.483	0.146	0.261	0.053	0.215	0.161	0.027	0.033	0.025	0.017
Cement and cement products	0.113	0.058	0.070	0.037	0.060	0.192	0.029	0.023	0.015	0.014
Glass and glass products	0.090	0.051	0.091	0.037	0.064	0.172	0.027	0.022	0.015	0.014
Other non-metallic mineral products	0.429	0.074	0.144	0.063	0.109	0.172	0.045	0.029	0.019	0.013
Iron and steel	0.117	0.041	0.131	0.045	0.050	0.176	0.029	0.027	0.014	0.014
Non-ferrous metal	0.066	0.061	0.111	0.058	0.072	0.172	0.044	0.041	0.025	0.015
Metal products	0.105	0.069	0.151	0.052	0.121	0.165	0.043	0.028	0.019	0.015

Table C-2. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Boilers, Engines and turbines	0.096	0.056	0.118	0.040	0.084	0.150	0.039	0.026	0.017	0.015
General machinery	0.089	0.062	0.096	0.044	0.079	0.173	0.048	0.026	0.019	0.015
Metal working machinery	0.090	0.070	0.123	0.040	0.114	0.171	0.038	0.024	0.018	0.015
Specialaized machinery	0.082	0.058	0.129	0.042	0.125	0.179	0.042	0.026	0.018	0.015
Heavy Electrical equipment	0.105	0.078	0.056	0.052	0.115	0.185	0.042	0.029	0.021	0.015
Television sets, radios,audios and communication equipment	0.121	0.066	0.149	0.073	0.078	0.173	0.047	0.031	0.022	0.019
Electronic computing equipment	0.132	0.060	0.042	0.060	0.060	0.185	0.048	0.041	0.024	0.023
Semiconductors and integrated circuits	0.115	0.066	0.066	0.047	0.110	0.158	0.031	0.025	0.018	0.012
Other electronics and electronic products	0.114	0.056	0.037	0.052	0.069	0.188	0.034	0.026	0.022	0.016
Household electrical equipment	0.256	0.057	0.070	0.069	0.109	0.189	0.032	0.027	0.021	0.015
Lighting fixtures, batteries, wiring and others	0.097	0.053	0.045	0.043	0.055	0.183	0.078	0.027	0.021	0.014
Motor vehicles	0.075	0.067	0.150	0.043	0.058	0.177	0.028	0.027	0.019	0.017
Motor cycles	0.072	0.091	0.089	0.043	0.085	0.185	0.033	0.037	0.018	0.018
Shipbuilding	0.159	0.053	0.184	0.045	0.055	0.169	0.035	0.031	0.016	0.017
Other transport equipment	0.088	0.033	0.041	0.018	0.042	0.181	0.033	0.031	0.017	0.014
Precision machines	0.096	0.054	0.021	0.032	0.055	0.173	0.036	0.028	0.018	0.013
Other manufacturing products	0.176	0.046	0.397	0.072	0.097	0.277	0.046	0.034	0.026	0.016
Electricity and gas	0.070	0.032	0.033	0.016	0.023	0.150	0.025	0.016	0.011	0.008
Water supply	0.119	0.048	0.062	0.018	0.036	0.127	0.015	0.011	0.011	0.013
Building construction	0.241	0.138	0.467	0.061	0.190	0.267	0.056	0.028	0.023	0.016
Other construction	0.146	0.087	0.079	0.053	0.167	0.258	0.049	0.024	0.019	0.015
Wholesale and retail trade	0.364	0.079	0.371	0.027	0.114	0.363	0.030	0.035	0.018	0.014
Transportation	0.258	0.074	0.353	0.023	0.069	0.228	0.032	0.025	0.016	0.014
Telephone and telecommunication	0.048	0.036	0.069	0.015	0.060	0.124	0.010	0.016	0.012	0.009
Finance and insurance	0.070	0.036	0.093	0.018	0.066	0.137	0.015	0.013	0.011	0.008
Real estate	0.047	0.079	0.031	0.024	0.113	0.071	0.012	0.008	0.003	0.004
Education and research	0.310	0.132	0.261	0.030	0.150	0.296	0.031	0.024	0.016	0.018
Medical and health service	0.386	0.126	0.192	0.028	0.206	0.266	0.027	0.022	0.019	0.016
Restraunts	0.391	0.182	0.301	0.072	0.238	0.543	0.073	0.057	0.042	0.027
Hotel	0.276	0.085	0.221	0.038	0.260	0.340	0.034	0.033	0.026	0.017
Other services	0.326	0.062	0.225	0.041	0.159	0.266	0.023	0.026	0.019	0.014
Public administration	0.310	0.127	0.169	0.033	0.153	0.281	0.015	0.020	0.011	0.014
Unclassified	0.226	0.039	-	-	0.146	0.231	0.021	0.031	0.010	0.021
AVG	**0.272**	**0.096**	**0.240**	**0.052**	**0.166**	**0.304**	**0.044**	**0.035**	**0.026**	**0.016**
SD	**0.284**	**0.122**	**0.325**	**0.043**	**0.176**	**0.229**	**0.028**	**0.023**	**0.020**	**0.008**

Table C-3. Paid worker intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	0.252	0.023	0.366	-	0.163	0.081	0.016	0.009	0.008	-
Other grain	0.201	0.027	0.309	-	0.163	0.086	0.012	0.015	0.014	0.012
Food crops	0.191	0.080	0.183	-	0.167	0.077	0.018	0.009	0.010	0.009
Non-food crops	0.210	0.047	0.079	0.068	0.139	0.074	0.018	0.006	0.014	0.010
Livestock and poultry	0.070	0.033	0.060	0.056	0.073	0.104	0.020	0.014	0.015	0.011
Forestry	0.088	0.022	0.374	-	0.088	0.079	0.025	0.015	0.009	0.009
Fishery	0.080	0.037	0.129	0.016	0.053	0.091	0.018	0.013	0.011	0.009
Crude petroleum and natural gas	0.006	0.008	0.007	-	0.014	0.046	0.007	0.005	0.009	0.007
Iron ore	0.186	0.057	-	-	0.181	0.076	0.014	0.011	0.009	0.008
Other metallic ore	0.028	0.060	0.081	-	0.178	0.068	0.030	0.027	0.011	0.008
Non-metallic ore and quarrying	0.042	0.048	0.067	-	0.037	0.073	0.008	0.011	0.012	0.009
Milled grain and flour	0.185	0.043	0.158	0.059	0.144	0.085	0.018	0.011	0.010	0.011
Fish products	0.077	0.053	0.102	0.042	0.083	0.089	0.031	0.024	0.016	0.022
Slaughtering, meat products and dairy products	0.103	0.054	0.048	0.037	0.068	0.106	0.017	0.015	0.016	0.013
Other food products	0.126	0.062	0.098	0.045	0.102	0.084	0.031	0.021	0.018	0.012
Beverage	0.131	0.051	0.082	0.028	0.034	0.073	0.017	0.010	0.009	0.012
Tobacco	0.100	0.046	0.046	0.030	0.017	0.036	0.004	0.004	0.003	0.004
Spinning	0.108	0.129	0.114	0.045	0.107	0.085	0.032	0.029	0.027	0.021
Weaving and dyeing	0.145	0.050	0.192	0.045	0.060	0.087	0.026	0.023	0.019	0.016
Knitting	0.077	0.067	0.068	0.045	0.078	0.083	0.022	0.024	0.023	0.016
Wearing apparel	0.250	0.118	0.179	0.063	0.086	0.078	0.049	0.025	0.024	0.020
Other made-up textile products	0.118	0.065	0.143	0.051	0.119	0.102	0.034	0.021	0.020	0.015
Leather and leather products	0.205	0.054	0.425	0.050	0.063	0.089	0.073	0.023	0.019	0.017
Timber	0.500	0.057	0.112	0.047	0.068	0.082	0.082	0.023	0.015	0.012
Wooden furniture	0.413	0.059	0.179	0.064	0.058	0.098	0.073	0.025	0.021	0.018
Other wooden products	0.152	0.073	0.190	0.059	0.139	0.084	0.043	0.026	0.017	0.015
Pulp and paper	0.060	0.062	0.141	0.034	0.053	0.083	0.026	0.017	0.015	0.011
Printing and publishing	0.159	0.071	0.136	0.028	0.095	0.078	0.023	0.019	0.014	0.009
Synthetic resins and fiber	0.019	0.016	0.070	0.018	0.032	0.090	0.020	0.013	0.011	0.010
Basic industrial chemicals	0.031	0.026	0.050	0.020	0.023	0.067	0.013	0.012	0.011	0.009
Chemical fertilizers and pesticides	0.023	0.032	0.052	0.020	0.074	0.079	0.024	0.019	0.012	0.009
Drugs and medicine	0.113	0.055	0.072	0.016	0.045	0.072	0.023	0.014	0.010	0.007
Other chemical products	0.082	0.038	0.071	0.021	0.046	0.071	0.019	0.015	0.012	0.009
Refined petroleum and its products	0.006	0.019	0.011	0.022	0.007	0.088	0.007	0.006	0.004	0.008
Plastic products	0.078	0.058	0.075	0.033	0.081	0.081	0.022	0.016	0.016	0.012
Tires and tubes	0.071	0.064	0.080	0.034	0.085	0.084	0.014	0.019	0.017	0.014
Other rubber products	0.120	0.077	0.182	0.034	0.129	0.067	0.018	0.020	0.015	0.013
Cement and cement products	0.073	0.042	0.046	0.023	0.043	0.084	0.019	0.015	0.013	0.012
Glass and glass products	0.057	0.038	0.069	0.026	0.042	0.079	0.016	0.014	0.011	0.012
Other non-metallic mineral products	0.239	0.060	0.105	0.040	0.073	0.077	0.031	0.019	0.014	0.011
Iron and steel	0.068	0.029	0.100	0.026	0.032	0.081	0.017	0.015	0.010	0.011
Non-ferrous metal	0.036	0.042	0.077	0.036	0.054	0.079	0.027	0.023	0.017	0.012
Metal products	0.052	0.051	0.108	0.036	0.088	0.076	0.029	0.018	0.015	0.013

Table C-3. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Boilers, Engines and turbines	0.038	0.039	0.090	0.029	0.059	0.069	0.030	0.018	0.013	0.012
General machinery	0.041	0.043	0.072	0.030	0.051	0.079	0.033	0.018	0.014	0.012
Metal working machinery	0.051	0.053	0.095	0.029	0.081	0.080	0.025	0.016	0.014	0.013
Specialaized machinery	0.035	0.036	0.099	0.030	0.089	0.080	0.029	0.018	0.014	0.012
Heavy Electrical equipment	0.047	0.060	0.043	0.033	0.077	0.084	0.029	0.019	0.016	0.012
Television sets, radios,audios and communication equipment	0.066	0.042	0.111	0.041	0.045	0.081	0.032	0.020	0.016	0.014
Electronic computing equipment	0.064	0.036	0.027	0.034	0.031	0.088	0.031	0.024	0.016	0.016
Semiconductors and integrated circuits	0.058	0.042	0.043	0.028	0.072	0.074	0.021	0.017	0.014	0.010
Other electronics and electronic products	0.057	0.038	0.024	0.030	0.038	0.087	0.025	0.017	0.016	0.013
Household electrical equipment	0.133	0.038	0.046	0.042	0.072	0.085	0.022	0.018	0.015	0.012
Lighting fixtures, batteries, wiring and others	0.052	0.036	0.032	0.028	0.034	0.081	0.064	0.018	0.015	0.012
Motor vehicles	0.038	0.046	0.093	0.028	0.033	0.082	0.020	0.017	0.014	0.013
Motor cycles	0.029	0.077	0.061	0.030	0.053	0.086	0.024	0.023	0.013	0.013
Shipbuilding	0.095	0.038	0.140	0.034	0.033	0.078	0.024	0.019	0.013	0.015
Other transport equipment	0.043	0.025	0.030	0.015	0.026	0.085	0.023	0.020	0.013	0.011
Precision machines	0.046	0.036	0.015	0.022	0.037	0.080	0.025	0.020	0.014	0.011
Other manufacturing products	0.077	0.032	0.214	0.042	0.059	0.084	0.030	0.020	0.016	0.012
Electricity and gas	0.039	0.023	0.024	0.009	0.015	0.072	0.014	0.009	0.008	0.007
Water supply	0.080	0.038	0.054	0.015	0.030	0.063	0.012	0.009	0.009	0.012
Building construction	0.151	0.106	0.413	0.046	0.152	0.089	0.041	0.021	0.017	0.013
Other construction	0.079	0.059	0.051	0.040	0.139	0.088	0.034	0.018	0.015	0.012
Wholesale and retail trade	0.086	0.047	0.114	0.021	0.045	0.174	0.017	0.017	0.015	0.013
Transportation	0.089	0.051	0.194	0.018	0.034	0.107	0.022	0.016	0.014	0.012
Telephone and telecommunication	0.032	0.029	0.057	0.012	0.050	0.065	0.008	0.011	0.010	0.008
Finance and insurance	0.054	0.028	0.076	0.015	0.055	0.072	0.014	0.011	0.009	0.007
Real estate	0.029	0.065	0.022	0.018	0.087	0.043	0.010	0.006	0.003	0.003
Education and research	0.269	0.121	0.244	0.024	0.134	0.130	0.027	0.020	0.015	0.016
Medical and health service	0.147	0.107	0.141	0.023	0.159	0.110	0.022	0.016	0.015	0.015
Restraunts	0.096	0.108	0.153	0.040	0.068	0.144	0.036	0.021	0.028	0.024
Hotel	0.117	0.075	0.154	0.032	0.092	0.139	0.029	0.019	0.018	0.015
Other services	0.183	0.037	0.160	0.032	0.082	0.119	0.016	0.018	0.016	0.012
Public administration	0.263	0.111	0.157	0.024	0.133	0.137	0.013	0.016	0.009	0.013
Unclassified	0.054	0.024	-	-	0.070	0.112	0.016	0.017	0.008	0.018
AVG	**0.106**	**0.052**	**0.112**	**0.029**	**0.075**	**0.086**	**0.025**	**0.017**	**0.014**	**0.012**
SD	**0.088**	**0.025**	**0.090**	**0.016**	**0.044**	**0.021**	**0.014**	**0.005**	**0.005**	**0.004**

Table C-4. Vulnerable employment intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	1.2E+00	1.0E+00	1.1E+00	0.0E+00	6.5E-01	8.0E-01	5.6E-02	7.3E-02	1.4E-01	0.0E+00
Other grain	9.4E-01	7.0E-02	1.9E+00	0.0E+00	6.3E-01	8.2E-01	1.4E-01	1.4E-01	9.2E-03	4.6E-03
Food crops	8.9E-01	7.0E-02	2.4E-01	0.0E+00	6.5E-01	7.8E-01	7.1E-02	5.7E-02	4.6E-02	4.0E-03
Non-food crops	9.7E-01	1.8E-01	3.1E-01	6.6E-02	5.6E-01	7.7E-01	5.0E-02	1.8E-02	3.9E-02	5.3E-03
Livestock and poultry	4.5E-01	3.0E-02	1.6E-01	7.7E-02	2.2E-01	9.1E-01	5.7E-02	5.4E-02	2.9E-02	7.0E-03
Forestry	1.5E-01	1.2E-02	7.4E-01	0.0E+00	3.3E-01	7.8E-01	7.2E-03	4.4E-02	5.6E-03	3.4E-03
Fishery	1.9E-01	7.0E-02	3.1E-01	4.9E-02	1.4E-01	8.4E-01	2.4E-02	2.2E-02	2.0E-02	5.4E-03
Crude petroleum and natural gas	1.8E-03	4.9E-03	3.9E-03	0.0E+00	1.2E-02	6.4E-02	1.1E-03	1.6E-03	1.9E-03	1.2E-03
Iron ore	2.1E-01	2.0E-02	0.0E+00	0.0E+00	2.6E-02	1.0E-01	1.3E-02	4.9E-03	1.6E-03	1.9E-03
Other metallic ore	2.4E-02	2.1E-02	3.5E-02	0.0E+00	9.7E-03	9.5E-02	3.7E-02	3.4E-03	2.0E-03	1.4E-03
Non-metallic ore and quarrying	4.4E-02	1.7E-02	3.1E-02	0.0E+00	1.1E-02	1.0E-01	4.0E-03	4.7E-03	3.0E-03	1.3E-03
Milled grain and flour	7.9E-01	4.2E-01	4.9E-01	2.3E-01	4.7E-01	4.3E-01	4.4E-02	8.3E-02	8.4E-02	2.6E-03
Fish products	1.4E-01	4.1E-02	1.2E-01	4.6E-02	9.0E-02	4.4E-01	3.3E-02	3.9E-02	2.0E-02	5.3E-02
Slaughtering, meat products and dairy products	2.6E-01	6.4E-02	7.1E-02	4.1E-02	1.4E-01	5.1E-01	3.5E-02	3.8E-02	2.0E-02	4.8E-03
Other food products	4.1E-01	6.7E-02	1.9E-01	7.6E-02	2.3E-01	3.8E-01	2.9E-02	5.7E-02	2.1E-02	4.2E-03
Beverage	3.5E-01	3.7E-02	8.7E-02	1.8E-02	4.5E-02	3.3E-01	1.1E-02	1.2E-02	7.7E-03	7.0E-03
Tobacco	8.7E-02	4.3E-02	2.5E-02	7.6E-02	3.1E-02	1.3E-01	2.6E-03	6.2E-03	5.1E-03	3.3E-03
Spinning	7.5E-02	2.7E-02	2.8E-01	5.6E-02	5.7E-02	2.3E-01	1.8E-02	4.3E-02	5.1E-02	4.5E-03
Weaving and dyeing	8.6E-02	2.4E-02	1.6E-01	5.6E-02	2.9E-02	2.6E-01	1.3E-02	1.9E-02	1.2E-02	7.9E-03
Knitting	6.4E-02	3.7E-02	9.1E-02	5.6E-02	4.4E-02	1.8E-01	1.3E-02	2.5E-02	1.8E-02	3.7E-03
Wearing apparel	1.0E-01	3.2E-02	1.5E-01	3.0E-02	4.2E-02	1.7E-01	1.5E-02	2.1E-02	2.1E-02	5.6E-03
Other made-up textile products	8.5E-02	3.1E-02	2.5E-01	2.1E-02	5.5E-02	2.1E-01	1.8E-02	1.8E-02	1.6E-02	5.5E-03
Leather and leather products	1.5E-01	2.8E-02	2.1E-01	5.7E-02	4.2E-02	2.9E-01	4.4E-02	2.4E-02	1.6E-02	8.9E-03
Timber	1.9E-01	1.2E-02	1.0E-01	3.8E-02	1.0E-01	8.0E-01	6.2E-02	3.2E-02	2.0E-02	2.8E-03
Wooden furniture	2.9E-01	1.3E-02	1.3E-01	3.0E-02	3.9E-02	1.6E-01	3.9E-02	2.1E-02	1.2E-02	5.5E-03
Other wooden products	2.0E-01	1.7E-02	3.1E-01	3.8E-02	1.0E-01	1.6E-01	4.9E-02	2.6E-02	1.2E-02	3.3E-03
Pulp and paper	5.9E-02	2.4E-02	1.4E-01	1.8E-02	4.0E-02	1.6E-01	1.7E-02	1.2E-02	7.1E-03	2.4E-03
Printing and publishing	8.9E-02	1.6E-02	5.8E-02	8.4E-03	4.2E-02	9.8E-02	1.2E-02	8.7E-03	3.5E-03	2.0E-03
Synthetic resins and fiber	2.6E-02	1.1E-02	3.0E-02	1.2E-02	3.8E-02	1.5E-01	9.8E-03	9.7E-03	5.8E-03	2.1E-03
Basic industrial chemicals	1.7E-02	1.8E-02	3.0E-02	1.5E-02	1.7E-02	8.8E-02	9.0E-03	9.5E-03	7.0E-03	2.0E-03
Chemical fertilizers and pesticides	1.4E-02	1.8E-02	2.5E-02	8.9E-03	3.7E-02	9.8E-02	1.4E-02	1.4E-02	7.8E-03	1.6E-03
Drugs and medicine	1.5E-01	2.0E-02	8.7E-02	1.0E-02	5.9E-02	1.9E-01	7.2E-03	9.3E-03	3.6E-03	8.5E-04
Other chemical products	1.2E-01	1.8E-02	7.7E-02	9.9E-03	3.9E-02	9.3E-02	9.7E-03	9.6E-03	5.0E-03	2.0E-03
Refined petroleum and its products	4.1E-03	1.3E-02	5.7E-03	2.0E-02	3.2E-03	1.0E-01	4.3E-03	4.5E-03	2.4E-03	1.6E-03
Plastic products	4.7E-02	1.6E-02	2.1E-02	1.1E-02	3.6E-02	1.1E-01	1.0E-02	7.7E-03	5.5E-03	2.2E-03
Tires and tubes	1.4E-01	4.4E-02	5.9E-02	1.8E-02	2.8E-01	1.1E-01	6.2E-03	3.0E-02	2.8E-02	5.9E-03
Other rubber products	3.6E-01	6.9E-02	7.9E-02	1.8E-02	8.6E-02	9.4E-02	9.5E-03	1.3E-02	9.7E-03	4.1E-03
Cement and cement products	4.0E-02	1.6E-02	2.4E-02	1.4E-02	1.7E-02	1.1E-01	1.0E-02	8.0E-03	2.6E-03	1.9E-03
Glass and glass products	3.3E-02	1.3E-02	2.2E-02	1.2E-02	2.3E-02	9.3E-02	1.1E-02	7.9E-03	3.4E-03	2.6E-03
Other non-metallic mineral products	1.9E-01	1.4E-02	3.9E-02	2.3E-02	3.6E-02	9.5E-02	1.4E-02	1.0E-02	5.1E-03	1.9E-03
Iron and steel	4.9E-02	1.2E-02	3.1E-02	1.9E-02	1.8E-02	9.5E-02	1.2E-02	1.2E-02	3.5E-03	2.7E-03
Non-ferrous metal	3.0E-02	1.9E-02	3.4E-02	2.2E-02	1.8E-02	9.3E-02	1.7E-02	1.8E-02	8.8E-03	2.4E-03

Table C-4. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Metal products	5.3E-02	1.8E-02	4.3E-02	1.6E-02	3.3E-02	8.9E-02	1.4E-02	9.8E-03	4.6E-03	2.3E-03
Boilers, Engines and turbines	5.8E-02	1.7E-02	2.8E-02	1.1E-02	2.5E-02	8.1E-02	8.8E-03	8.2E-03	4.1E-03	2.9E-03
General machinery	4.8E-02	1.9E-02	2.5E-02	1.3E-02	2.8E-02	9.3E-02	1.5E-02	8.5E-03	4.8E-03	2.5E-03
Metal working machinery	3.9E-02	1.8E-02	2.7E-02	1.1E-02	3.3E-02	9.2E-02	1.4E-02	7.7E-03	3.5E-03	2.1E-03
Specialaized machinery	4.7E-02	2.1E-02	3.0E-02	1.2E-02	3.6E-02	9.9E-02	1.3E-02	8.3E-03	4.5E-03	3.0E-03
Heavy Electrical equipment	5.8E-02	1.8E-02	1.3E-02	2.0E-02	3.8E-02	1.0E-01	1.4E-02	9.8E-03	5.7E-03	2.4E-03
Television sets, radios,audios and communication equipment	5.6E-02	2.4E-02	3.8E-02	3.2E-02	3.2E-02	9.2E-02	1.5E-02	1.1E-02	6.6E-03	4.9E-03
Electronic computing equipment	6.8E-02	2.4E-02	1.6E-02	2.6E-02	3.0E-02	9.7E-02	1.7E-02	1.7E-02	7.4E-03	6.9E-03
Semiconductors and integrated circuits	5.7E-02	2.4E-02	2.4E-02	1.9E-02	3.8E-02	8.4E-02	1.0E-02	8.3E-03	4.6E-03	1.8E-03
Other electronics and electronic products	5.7E-02	1.8E-02	1.4E-02	2.3E-02	3.1E-02	1.0E-01	9.7E-03	8.8E-03	6.2E-03	3.1E-03
Household electrical equipment	1.2E-01	1.8E-02	2.4E-02	2.7E-02	3.7E-02	1.0E-01	1.1E-02	9.7E-03	6.3E-03	2.7E-03
Lighting fixtures, batteries, wiring and others	4.5E-02	1.7E-02	1.3E-02	1.5E-02	2.1E-02	1.0E-01	1.5E-02	9.4E-03	5.8E-03	2.8E-03
Motor vehicles	3.7E-02	2.1E-02	5.8E-02	1.4E-02	2.5E-02	9.6E-02	8.0E-03	9.7E-03	4.6E-03	4.0E-03
Motor cycles	4.3E-02	1.4E-02	2.8E-02	1.2E-02	3.2E-02	9.9E-02	9.5E-03	1.4E-02	4.6E-03	4.7E-03
Shipbuilding	6.4E-02	1.5E-02	4.4E-02	1.1E-02	2.2E-02	9.1E-02	1.1E-02	1.1E-02	3.7E-03	2.2E-03
Other transport equipment	4.5E-02	8.3E-03	1.1E-02	2.6E-03	1.6E-02	9.6E-02	9.6E-03	1.1E-02	3.7E-03	2.4E-03
Precision machines	5.1E-02	1.8E-02	5.9E-03	1.0E-02	1.8E-02	9.3E-02	1.1E-02	7.9E-03	4.3E-03	2.1E-03
Other manufacturing products	9.9E-02	1.4E-02	1.8E-01	3.0E-02	3.9E-02	1.9E-01	1.6E-02	1.4E-02	1.0E-02	3.2E-03
Electricity and gas	3.1E-02	9.8E-03	8.9E-03	6.7E-03	7.8E-03	7.8E-02	1.1E-02	6.5E-03	2.9E-03	8.1E-04
Water supply	3.9E-02	1.0E-02	7.9E-03	3.1E-03	5.3E-03	6.4E-02	2.5E-03	2.5E-03	2.2E-03	6.8E-04
Building construction	8.9E-02	3.2E-02	5.4E-02	1.5E-02	3.7E-02	1.8E-01	1.5E-02	6.5E-03	6.3E-03	3.2E-03
Other construction	6.6E-02	2.8E-02	2.9E-02	1.3E-02	2.8E-02	1.7E-01	1.5E-02	5.8E-03	4.3E-03	3.1E-03
Wholesale and retail trade	2.8E-01	3.2E-02	2.6E-01	5.6E-03	6.9E-02	1.9E-01	1.3E-02	1.8E-02	2.7E-03	1.4E-03
Transportation	1.7E-01	2.3E-02	1.6E-01	4.2E-03	3.5E-02	1.2E-01	9.8E-03	8.4E-03	2.1E-03	1.8E-03
Telephone and telecommunication	1.6E-02	6.3E-03	1.2E-02	3.0E-03	9.4E-03	5.9E-02	1.9E-03	4.7E-03	2.2E-03	1.1E-03
Finance and insurance	1.6E-02	8.1E-03	1.7E-02	3.6E-03	1.1E-02	6.6E-02	1.1E-03	1.8E-03	1.7E-03	7.1E-04
Real estate	1.8E-02	1.4E-02	9.6E-03	5.4E-03	2.6E-02	2.8E-02	1.9E-03	2.0E-03	8.7E-04	6.5E-04
Education and research	4.1E-02	1.1E-02	1.7E-02	5.5E-03	1.6E-02	1.7E-01	4.2E-03	4.0E-03	9.2E-04	1.8E-03
Medical and health service	2.4E-01	1.9E-02	5.1E-02	5.0E-03	4.7E-02	1.6E-01	4.8E-03	5.9E-03	3.5E-03	1.5E-03
Restraunts	2.9E-01	7.4E-02	1.5E-01	3.2E-02	1.7E-01	4.0E-01	3.7E-02	3.6E-02	1.4E-02	2.8E-03
Hotel	1.6E-01	1.0E-02	6.8E-02	4.9E-03	1.7E-01	2.0E-01	5.1E-03	1.4E-02	7.7E-03	1.3E-03
Other services	1.4E-01	2.4E-02	6.5E-02	9.2E-03	7.7E-02	1.5E-01	6.8E-03	7.5E-03	3.5E-03	1.8E-03
Public administration	4.7E-02	1.6E-02	1.2E-02	8.7E-03	2.0E-02	1.4E-01	1.7E-03	3.9E-03	1.4E-03	1.2E-03
Unclassified	1.7E-01	1.5E-02	0.0E+00	0.0E+00	7.6E-02	1.2E-01	5.1E-03	1.4E-02	2.2E-03	2.8E-03
AVG	**1.7E-01**	**4.5E-02**	**1.3E-01**	**2.3E-02**	**9.1E-02**	**2.2E-01**	**1.9E-02**	**1.8E-02**	**1.2E-02**	**3.7E-03**
SD	**0.234**	**0.122**	**0.264**	**0.030**	**0.149**	**0.225**	**0.021**	**0.022**	**0.020**	**0.006**

Table C-5. Wages intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	0.20	0.48	0.21	-	0.32	0.21	0.42	0.10	0.23	-
Other grain	0.16	0.25	0.27	-	0.39	0.22	0.34	0.12	0.35	0.39
Food crops	0.21	0.42	0.25	-	0.27	0.19	0.51	0.17	0.25	0.36
Non-food crops	0.38	0.25	0.29	0.49	0.26	0.19	0.47	0.17	0.28	0.44
Livestock and poultry	0.34	0.26	0.22	0.47	0.26	0.26	0.34	0.24	0.38	0.39
Forestry	0.23	0.17	0.19	-	0.28	0.19	0.57	0.18	0.26	0.42
Fishery	0.21	0.24	0.21	0.44	0.24	0.29	0.42	0.43	0.36	0.37
Crude petroleum and natural gas	0.08	0.07	0.14	-	0.26	0.15	0.21	0.10	0.48	0.40
Iron ore	0.33	0.34	-	-	0.31	0.26	0.29	0.38	0.48	0.54
Other metallic ore	0.18	0.31	0.24	-	0.27	0.27	0.32	0.28	0.48	0.56
Non-metallic ore and quarrying	0.28	0.29	0.28	-	0.27	0.32	0.38	0.39	0.47	0.53
Milled grain and flour	0.20	0.35	0.18	0.43	0.33	0.23	0.38	0.14	0.30	0.51
Fish products	0.22	0.28	0.20	0.45	0.29	0.29	0.42	0.43	0.42	0.60
Slaughtering, meat products and dairy products	0.31	0.29	0.20	0.45	0.28	0.27	0.39	0.30	0.44	0.52
Other food products	0.28	0.32	0.17	0.43	0.29	0.25	0.40	0.35	0.49	0.53
Beverage	0.32	0.28	0.15	0.46	0.21	0.22	0.29	0.26	0.33	0.50
Tobacco	0.18	0.28	0.06	0.36	0.11	0.07	0.11	0.12	0.11	0.15
Spinning	0.25	0.32	0.27	0.47	0.32	0.31	0.41	0.42	0.49	0.81
Weaving and dyeing	0.29	0.28	0.23	0.47	0.33	0.30	0.41	0.44	0.57	0.63
Knitting	0.28	0.29	0.24	0.47	0.36	0.33	0.40	0.42	0.59	0.68
Wearing apparel	0.29	0.29	0.24	0.53	0.33	0.37	0.53	0.46	0.58	0.56
Other made-up textile products	0.34	0.29	0.33	0.59	0.32	0.33	0.44	0.44	0.58	0.58
Leather and leather products	0.39	0.31	0.31	0.47	0.34	0.34	0.46	0.47	0.55	0.61
Timber	0.31	0.24	0.26	0.52	0.30	0.27	0.38	0.42	0.43	0.52
Wooden furniture	0.29	0.27	0.28	0.58	0.36	0.32	0.45	0.47	0.59	0.65
Other wooden products	0.28	0.26	0.26	0.52	0.32	0.30	0.43	0.45	0.52	0.62
Pulp and paper	0.30	0.33	0.26	0.47	0.30	0.30	0.41	0.41	0.48	0.53
Printing and publishing	0.30	0.30	0.29	0.46	0.32	0.31	0.46	0.49	0.58	0.59
Synthetic resins and fiber	0.21	0.14	0.24	0.32	0.32	0.28	0.32	0.33	0.43	0.55
Basic industrial chemicals	0.23	0.22	0.22	0.29	0.31	0.26	0.26	0.28	0.37	0.53
Chemical fertilizers and pesticides	0.27	0.27	0.23	0.40	0.29	0.27	0.40	0.38	0.42	0.47
Drugs and medicine	0.29	0.30	0.28	0.18	0.30	0.25	0.38	0.40	0.47	0.41
Other chemical products	0.29	0.25	0.21	0.43	0.31	0.29	0.37	0.39	0.49	0.50
Refined petroleum and its products	0.32	0.15	0.12	0.26	0.22	0.27	0.11	0.13	0.12	0.45
Plastic products	0.27	0.31	0.25	0.49	0.31	0.30	0.39	0.43	0.57	0.57
Tires and tubes	0.32	0.33	0.26	0.44	0.28	0.32	0.41	0.40	0.46	0.69
Other rubber products	0.34	0.31	0.28	0.44	0.35	0.28	0.36	0.46	0.55	0.64
Cement and cement products	0.27	0.27	0.18	0.46	0.26	0.30	0.32	0.41	0.51	0.57
Glass and glass products	0.30	0.31	0.23	0.36	0.32	0.29	0.29	0.38	0.48	0.58
Other non-metallic mineral products	0.34	0.29	0.21	0.50	0.30	0.30	0.39	0.43	0.51	0.55
Iron and steel	0.22	0.26	0.21	0.34	0.32	0.26	0.30	0.33	0.42	0.63
Non-ferrous metal	0.24	0.31	0.23	0.45	0.31	0.27	0.38	0.40	0.48	0.62
Metal products	0.31	0.31	0.26	0.46	0.32	0.30	0.42	0.44	0.58	0.64

Table C-5. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Boilers, Engines and turbines	0.35	0.32	0.28	0.49	0.35	0.26	0.46	0.48	0.54	0.54
General machinery	0.38	0.33	0.32	0.42	0.33	0.31	0.40	0.48	0.57	0.63
Metal working machinery	0.39	0.36	0.29	0.49	0.39	0.33	0.43	0.47	0.62	0.66
Specialaized machinery	0.38	0.33	0.28	0.49	0.39	0.31	0.43	0.48	0.56	0.61
Heavy Electrical equipment	0.36	0.39	0.32	0.45	0.40	0.31	0.43	0.49	0.61	0.58
Television sets, radios,audios and communication equipment	0.27	0.42	0.31	0.41	0.39	0.35	0.44	0.44	0.57	0.60
Electronic computing equipment	0.28	0.33	0.38	0.36	0.31	0.34	0.41	0.46	0.54	0.53
Semiconductors and integrated circuits	0.27	0.36	0.30	0.38	0.39	0.35	0.36	0.38	0.58	0.50
Other electronics and electronic products	0.27	0.34	0.35	0.36	0.31	0.33	0.38	0.45	0.57	0.67
Household electrical equipment	0.33	0.36	0.32	0.37	0.33	0.28	0.43	0.44	0.52	0.57
Lighting fixtures, batteries, wiring and others	0.28	0.32	0.31	0.41	0.29	0.32	0.44	0.45	0.55	0.56
Motor vehicles	0.35	0.36	0.31	0.51	0.32	0.29	0.32	0.47	0.60	0.56
Motor cycles	0.36	0.36	0.30	0.51	0.31	0.34	0.37	0.43	0.58	0.60
Shipbuilding	0.35	0.32	0.25	0.49	0.39	0.39	0.49	0.53	0.52	0.68
Other transport equipment	0.40	0.23	0.30	0.51	0.36	0.34	0.49	0.48	0.57	0.63
Precision machines	0.36	0.38	0.35	0.38	0.35	0.33	0.46	0.49	0.59	0.59
Other manufacturing products	0.34	0.23	0.27	0.46	0.34	0.32	0.46	0.48	0.55	0.61
Electricity and gas	0.30	0.16	0.20	0.23	0.32	0.26	0.20	0.24	0.36	0.39
Water supply	0.36	0.20	0.29	0.32	0.35	0.33	0.36	0.33	0.40	0.41
Building construction	0.31	0.41	0.25	0.58	0.34	0.34	0.47	0.51	0.65	0.61
Other construction	0.35	0.41	0.24	0.56	0.31	0.35	0.45	0.49	0.62	0.69
Wholesale and retail trade	0.28	0.32	0.19	0.45	0.26	0.28	0.48	0.41	0.55	0.55
Transportation	0.37	0.30	0.30	0.41	0.32	0.27	0.42	0.43	0.56	0.63
Telephone and telecommunication	0.22	0.24	0.17	0.32	0.30	0.24	0.19	0.37	0.43	0.51
Finance and insurance	0.30	0.27	0.19	0.45	0.33	0.37	0.34	0.39	0.47	0.54
Real estate	0.10	0.15	0.07	0.38	0.15	0.16	0.21	0.15	0.11	0.16
Education and research	0.61	0.60	0.45	0.65	0.72	0.57	0.77	0.73	0.77	0.71
Medical and health service	0.42	0.41	0.40	0.60	0.48	0.39	0.57	0.55	0.66	0.69
Restraunts	0.31	0.42	0.23	0.55	0.26	0.27	0.53	0.37	0.54	0.60
Hotel	0.29	0.34	0.22	0.47	0.32	0.26	0.47	0.40	0.51	0.54
Other services	0.37	0.43	0.27	0.57	0.37	0.34	0.35	0.53	0.55	0.56
Public administration	0.66	0.56	0.67	0.67	0.69	0.61	0.72	0.64	0.57	0.75
Unclassified	0.25	0.22	-	-	0.30	0.19	0.41	0.45	0.40	0.82
AVG	**0.30**	**0.31**	**0.25**	**0.40**	**0.32**	**0.29**	**0.40**	**0.39**	**0.48**	**0.55**
SD	**0.09**	**0.09**	**0.09**	**0.17**	**0.08**	**0.07**	**0.11**	**0.13**	**0.13**	**0.13**

Table C-6. Fatal intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	3.91E-05	5.26E-06	2.02E-05	0.00E+00	7.89E-06	3.85E-05	2.15E-05	2.30E-06	1.44E-06	0.00E+00
Other grain	3.20E-05	1.26E-05	1.69E-05	0.00E+00	9.11E-06	4.22E-05	4.89E-05	3.56E-06	2.48E-06	3.13E-06
Food crops	3.02E-05	3.82E-05	1.77E-05	0.00E+00	8.62E-06	3.51E-05	2.86E-05	3.07E-06	1.98E-06	5.69E-06
Non-food crops	3.36E-05	2.88E-05	1.38E-05	4.03E-06	5.55E-06	3.29E-05	2.06E-05	2.83E-06	2.86E-06	6.38E-06
Livestock and poultry	1.69E-05	9.00E-06	1.21E-05	4.51E-06	1.90E-05	3.92E-05	1.83E-05	4.07E-06	2.26E-06	4.64E-06
Forestry	2.04E-04	4.76E-06	9.11E-05	0.00E+00	2.93E-05	3.32E-05	1.04E-05	1.40E-05	1.61E-06	5.25E-06
Fishery	1.42E-05	1.43E-05	1.62E-04	3.17E-06	6.15E-06	3.48E-05	1.02E-05	4.80E-06	3.16E-06	2.55E-05
Crude petroleum and natural gas	6.03E-07	2.00E-06	6.05E-06	0.00E+00	4.67E-06	2.63E-05	2.29E-06	3.86E-06	2.02E-06	1.03E-06
Iron ore	1.62E-04	1.06E-05	0.00E+00	0.00E+00	9.77E-06	2.57E-04	2.55E-05	7.29E-06	1.05E-06	1.46E-06
Other metallic ore	2.09E-05	1.07E-05	9.20E-05	0.00E+00	5.28E-06	2.38E-04	1.03E-04	2.67E-05	7.15E-06	9.46E-07
Non-metallic ore and quarrying	3.41E-05	7.99E-06	1.13E-04	0.00E+00	5.77E-05	2.61E-04	4.10E-06	8.27E-06	3.65E-06	1.90E-06
Milled grain and flour	3.62E-05	9.70E-06	2.14E-05	1.26E-05	2.03E-05	4.70E-05	1.33E-05	3.59E-06	1.46E-06	2.07E-06
Fish products	2.59E-05	1.17E-05	7.64E-05	7.63E-06	1.18E-05	4.74E-05	1.20E-05	7.80E-06	3.22E-06	6.77E-06
Slaughtering, meat products and dairy products	4.20E-05	1.20E-05	1.52E-05	6.76E-06	1.90E-05	5.09E-05	1.16E-05	4.41E-06	2.22E-06	2.96E-06
Other food products	3.90E-05	2.12E-05	2.08E-05	9.89E-06	1.47E-05	4.68E-05	9.30E-06	7.00E-06	2.28E-06	1.87E-06
Beverage	4.21E-05	1.15E-05	2.40E-05	5.20E-06	9.34E-06	4.07E-05	5.56E-06	3.33E-06	1.31E-06	2.04E-06
Tobacco	4.53E-05	1.09E-05	1.47E-05	6.86E-06	1.71E-06	2.18E-05	1.40E-06	1.39E-06	4.70E-07	6.25E-07
Spinning	5.10E-05	1.31E-05	3.00E-05	1.14E-05	1.39E-05	4.30E-05	9.51E-06	9.82E-06	6.00E-06	3.34E-06
Weaving and dyeing	7.21E-05	9.91E-06	6.60E-05	1.15E-05	1.08E-05	4.31E-05	8.33E-06	8.65E-06	3.53E-06	2.61E-06
Knitting	3.73E-05	1.09E-05	2.70E-05	1.15E-05	1.66E-05	4.50E-05	7.29E-06	8.04E-06	3.67E-06	1.75E-06
Wearing apparel	1.31E-04	1.35E-05	6.01E-05	1.15E-05	1.82E-05	3.76E-05	9.72E-06	7.64E-06	4.07E-06	1.54E-06
Other made-up textile products	5.83E-05	1.02E-05	3.97E-05	8.08E-06	1.24E-05	5.00E-05	9.39E-06	7.19E-06	3.09E-06	1.96E-06
Leather and leather products	1.01E-04	9.77E-06	1.39E-04	1.49E-05	1.29E-05	4.03E-05	1.46E-05	7.34E-06	2.62E-06	2.33E-06
Timber	3.16E-04	9.42E-06	4.30E-05	1.74E-05	5.63E-05	8.02E-05	2.32E-05	1.15E-05	2.61E-06	3.79E-06
Wooden furniture	2.42E-04	1.02E-05	6.16E-05	1.45E-05	1.59E-05	6.62E-05	1.71E-05	9.16E-06	4.38E-06	2.59E-06
Other wooden products	1.03E-04	1.32E-05	6.21E-05	1.80E-05	1.46E-05	7.00E-05	1.52E-05	9.91E-06	2.84E-06	2.22E-06
Pulp and paper	3.12E-05	1.05E-05	4.39E-05	8.47E-06	1.46E-05	6.96E-05	9.18E-06	7.52E-06	3.13E-06	1.55E-06
Printing and publishing	7.76E-05	7.96E-06	4.63E-05	4.11E-06	2.75E-05	6.33E-05	6.12E-06	3.86E-06	1.35E-06	9.04E-07
Synthetic resins and fiber	8.16E-06	4.63E-06	3.52E-05	5.79E-06	1.61E-05	8.14E-05	9.49E-06	7.76E-06	3.73E-06	1.44E-06
Basic industrial chemicals	1.50E-05	7.54E-06	2.50E-05	7.16E-06	7.64E-06	8.65E-05	8.02E-06	8.64E-06	4.49E-06	1.29E-06
Chemical fertilizers and pesticides	1.08E-05	7.73E-06	2.47E-05	4.61E-06	5.78E-05	1.15E-04	1.19E-05	1.22E-05	3.54E-06	1.16E-06
Drugs and medicine	4.65E-05	7.88E-06	2.22E-05	3.78E-06	9.06E-06	7.65E-05	5.76E-06	4.17E-06	1.41E-06	4.73E-07
Other chemical products	3.41E-05	7.81E-06	2.16E-05	5.04E-06	1.19E-05	7.47E-05	7.20E-06	6.75E-06	2.78E-06	1.27E-06
Refined petroleum and its products	3.69E-06	4.87E-06	8.52E-06	9.36E-06	2.27E-06	4.16E-05	9.40E-06	9.09E-06	5.63E-06	1.09E-06
Plastic products	3.63E-05	8.15E-06	2.71E-05	5.90E-06	2.12E-05	7.37E-05	7.59E-06	6.39E-06	3.00E-06	1.47E-06
Tires and tubes	2.65E-05	1.27E-05	2.83E-05	6.67E-06	1.10E-05	7.90E-05	4.68E-06	6.94E-06	3.41E-06	2.13E-06
Other rubber products	3.54E-05	1.36E-05	6.01E-05	6.87E-06	1.68E-05	6.77E-05	6.66E-06	7.08E-06	2.25E-06	1.84E-06
Cement and cement products	4.01E-05	9.65E-06	2.32E-05	6.58E-06	4.25E-05	7.25E-05	1.19E-05	8.35E-06	2.08E-06	2.08E-06
Glass and glass products	2.99E-05	9.00E-06	2.87E-05	6.20E-06	1.43E-05	7.33E-05	1.66E-05	8.22E-06	2.40E-06	1.69E-06
Other non-metallic mineral products	1.29E-04	1.12E-05	4.21E-05	1.19E-05	2.40E-05	7.52E-05	1.99E-05	1.27E-05	2.98E-06	1.77E-06
Iron and steel	3.17E-05	7.37E-06	7.32E-05	1.16E-05	2.00E-05	6.84E-05	1.01E-05	9.24E-06	2.75E-06	1.92E-06
Non-ferrous metal	2.13E-05	1.08E-05	7.54E-05	1.17E-05	2.46E-05	7.33E-05	1.22E-05	1.73E-05	7.68E-06	1.87E-06
Metal products	2.51E-05	9.92E-06	5.10E-05	9.11E-06	2.86E-05	5.28E-05	9.06E-06	8.25E-06	2.35E-06	1.44E-06

Table C-6. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Boilers, Engines and turbines	1.55E-05	9.62E-06	4.18E-05	4.98E-06	1.07E-05	4.72E-05	6.97E-06	6.45E-06	2.14E-06	1.87E-06
General machinery	1.70E-05	1.00E-05	2.89E-05	6.27E-06	1.44E-05	4.71E-05	9.68E-06	6.71E-06	2.41E-06	1.35E-06
Metal working machinery	2.25E-05	1.01E-05	4.12E-05	4.99E-06	9.15E-06	4.65E-05	8.75E-06	5.70E-06	1.64E-06	1.12E-06
Specialaized machinery	1.44E-05	9.09E-06	4.52E-05	5.62E-06	2.94E-05	4.40E-05	8.52E-06	6.34E-06	2.04E-06	1.56E-06
Heavy Electrical equipment	2.01E-05	9.99E-06	1.65E-05	9.32E-06	1.69E-05	4.98E-05	9.16E-06	6.66E-06	2.71E-06	1.61E-06
Television sets, radios,audios and communication equipment	2.95E-05	1.03E-05	3.70E-05	1.24E-05	1.64E-05	3.47E-05	8.52E-06	5.60E-06	2.97E-06	2.15E-06
Electronic computing equipment	2.73E-05	1.01E-05	1.07E-05	1.02E-05	1.12E-05	3.68E-05	8.91E-06	7.34E-06	3.21E-06	2.83E-06
Semiconductors and integrated circuits	2.54E-05	1.02E-05	1.84E-05	7.77E-06	1.32E-05	3.64E-05	6.29E-06	4.62E-06	2.27E-06	1.05E-06
Other electronics and electronic products	2.49E-05	8.22E-06	1.03E-05	9.25E-06	1.18E-05	4.45E-05	7.16E-06	5.32E-06	3.00E-06	1.50E-06
Household electrical equipment	6.64E-05	8.52E-06	2.10E-05	1.21E-05	2.11E-05	4.89E-05	6.57E-06	5.96E-06	2.99E-06	1.73E-06
Lighting fixtures, batteries, wiring and others	2.26E-05	8.59E-06	1.50E-05	7.49E-06	9.96E-06	5.35E-05	1.31E-05	6.40E-06	3.10E-06	1.59E-06
Motor vehicles	1.58E-05	9.85E-06	3.08E-05	5.28E-06	1.01E-05	4.48E-05	5.38E-06	5.59E-06	1.99E-06	1.51E-06
Motor cycles	1.07E-05	9.66E-06	2.18E-05	5.29E-06	1.27E-05	4.19E-05	6.44E-06	7.13E-06	1.97E-06	2.43E-06
Shipbuilding	4.84E-05	8.39E-06	5.27E-05	7.88E-06	9.00E-06	4.09E-05	7.28E-06	8.62E-06	1.90E-06	1.53E-06
Other transport equipment	1.82E-05	4.51E-06	9.62E-06	1.31E-06	7.27E-06	4.49E-05	6.32E-06	6.58E-06	1.87E-06	1.37E-06
Precision machines	2.07E-05	8.04E-06	5.55E-06	4.50E-06	7.50E-06	4.09E-05	7.05E-06	4.90E-06	1.95E-06	1.02E-06
Other manufacturing products	3.78E-05	7.47E-06	1.04E-04	1.06E-05	1.35E-05	4.45E-05	8.71E-06	1.27E-05	2.46E-06	1.29E-06
Electricity and gas	1.32E-05	4.99E-06	5.87E-05	3.16E-06	7.74E-06	1.10E-04	2.16E-05	1.25E-05	3.20E-06	7.40E-07
Water supply	2.07E-05	5.83E-06	3.08E-05	1.49E-06	3.15E-06	6.28E-05	3.22E-06	2.83E-06	1.08E-06	4.75E-07
Building construction	1.47E-04	2.33E-05	1.19E-04	9.20E-06	6.34E-05	1.05E-04	1.23E-05	8.90E-06	2.80E-06	2.44E-06
Other construction	6.18E-05	1.46E-05	2.12E-05	7.09E-06	6.35E-05	1.03E-04	1.11E-05	7.91E-06	2.24E-06	1.56E-06
Wholesale and retail trade	1.98E-05	9.49E-06	6.85E-05	1.99E-06	1.41E-05	4.29E-05	2.10E-06	2.72E-06	7.29E-07	7.01E-07
Transportation	5.63E-05	2.06E-05	5.89E-05	3.03E-06	2.83E-05	4.89E-05	5.82E-06	5.62E-06	1.79E-06	1.93E-06
Telephone and telecommunication	7.83E-06	3.81E-06	2.08E-05	2.26E-06	6.15E-06	2.92E-05	1.78E-06	2.26E-06	9.42E-07	6.40E-07
Finance and insurance	1.12E-05	4.24E-06	1.41E-05	1.57E-06	6.95E-06	1.75E-05	8.95E-07	1.13E-06	4.28E-07	2.93E-07
Real estate	1.67E-05	7.38E-06	7.93E-06	2.57E-06	3.68E-06	1.51E-05	1.01E-06	1.24E-06	2.12E-07	2.54E-07
Education and research	4.91E-05	1.06E-05	1.72E-05	2.00E-06	1.17E-05	3.22E-05	3.58E-06	1.47E-06	4.26E-07	6.57E-07
Medical and health service	2.92E-05	1.12E-05	1.87E-05	1.93E-06	1.23E-05	5.03E-05	3.31E-06	2.31E-06	7.95E-07	4.59E-07
Restraunts	2.22E-05	5.93E-06	2.35E-05	3.89E-06	1.19E-05	3.76E-05	7.00E-06	4.68E-06	1.53E-06	9.90E-07
Hotel	2.31E-05	3.37E-06	2.67E-05	1.69E-06	1.26E-05	4.02E-05	4.19E-06	3.99E-06	1.20E-06	6.92E-07
Other services	3.24E-05	6.60E-06	5.00E-05	3.68E-06	2.96E-05	4.01E-05	1.84E-06	3.45E-06	7.20E-07	6.12E-07
Public administration	4.80E-05	1.95E-05	4.66E-05	3.22E-06	8.34E-06	3.68E-05	1.82E-06	3.05E-06	5.44E-07	8.41E-07
Unclassified	1.45E-05	6.01E-06	0.00E+00	0.00E+00	1.40E-05	4.75E-05	2.72E-06	5.74E-06	8.77E-07	2.37E-06
AVG	**4.66E-05**	**1.03E-05**	**3.92E-05**	**6.29E-06**	**1.69E-05**	**6.02E-05**	**1.11E-05**	**6.77E-06**	**2.48E-06**	**2.14E-06**
SD	**5.36E-05**	**5.46E-06**	**3.20E-05**	**4.38E-06**	**1.36E-05**	**4.42E-05**	**1.29E-05**	**3.92E-06**	**1.40E-06**	**3.01E-06**

Table C-7. Non-fatal intensity of 10 Asian countries for 76 industrial sectors based on the AIIO

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Paddy	1.1E-02	1.7E-02	1.9E-02	0.0E+00	1.1E-02	5.0E-03	1.0E-03	3.0E-03	2.6E-04	0.0E+00
Other grain	8.6E-03	3.9E-03	2.8E-02	0.0E+00	1.1E-02	5.6E-03	2.0E-03	5.7E-03	4.4E-04	1.8E-04
Food crops	8.1E-03	6.3E-03	7.2E-03	0.0E+00	1.2E-02	4.4E-03	1.3E-03	2.4E-03	3.5E-04	2.2E-04
Non-food crops	9.0E-03	9.7E-03	5.7E-03	1.1E-03	1.0E-02	4.0E-03	1.2E-03	9.3E-04	5.1E-04	2.2E-04
Livestock and poultry	4.5E-03	2.2E-03	8.1E-03	1.4E-03	5.9E-03	4.5E-03	1.3E-03	1.8E-03	4.7E-04	2.1E-04
Forestry	5.5E-02	1.4E-03	1.5E-02	0.0E+00	6.3E-03	4.1E-03	5.8E-04	2.1E-03	1.3E-03	2.3E-04
Fishery	3.8E-03	4.4E-03	9.9E-03	9.4E-04	3.0E-03	4.1E-03	8.8E-04	1.1E-03	5.1E-04	1.9E-04
Crude petroleum and natural gas	3.0E-04	3.7E-04	6.0E-04	0.0E+00	4.8E-04	4.3E-03	3.3E-04	2.2E-04	4.1E-04	1.5E-04
Iron ore	4.4E-02	1.8E-03	0.0E+00	0.0E+00	3.6E-03	3.2E-02	3.7E-03	4.4E-04	1.9E-04	2.5E-04
Other metallic ore	5.6E-03	1.8E-03	4.6E-03	0.0E+00	4.6E-03	3.0E-02	1.5E-02	1.0E-03	5.7E-04	1.5E-04
Non-metallic ore and quarrying	9.2E-03	1.5E-03	4.5E-03	0.0E+00	1.4E-03	3.3E-02	6.4E-04	5.8E-04	5.5E-04	2.7E-04
Milled grain and flour	9.7E-03	8.0E-03	1.1E-02	3.4E-03	9.0E-03	9.1E-03	9.9E-04	2.7E-03	2.7E-04	2.9E-04
Fish products	7.0E-03	3.2E-03	1.7E-02	1.8E-03	3.3E-03	8.9E-03	1.2E-03	1.2E-03	5.9E-04	7.9E-04
Slaughtering, meat products and dairy products	1.1E-02	3.0E-03	8.2E-03	1.9E-03	4.1E-03	9.3E-03	9.2E-04	1.3E-03	4.7E-04	2.7E-04
Other food products	1.0E-02	4.0E-03	1.7E-02	2.2E-03	5.4E-03	9.2E-03	1.2E-03	1.4E-03	5.1E-04	2.9E-04
Beverage	1.1E-02	2.8E-03	1.0E-02	1.1E-03	1.7E-03	8.2E-03	7.5E-04	5.2E-04	2.9E-04	5.0E-04
Tobacco	1.2E-02	2.8E-03	7.6E-03	1.7E-03	8.2E-04	5.0E-03	1.9E-04	2.6E-04	1.2E-04	1.2E-04
Spinning	1.3E-02	3.1E-03	2.4E-02	3.0E-03	3.5E-03	8.6E-03	1.6E-03	1.6E-03	1.5E-03	4.6E-04
Weaving and dyeing	1.9E-02	2.1E-03	4.5E-02	2.8E-03	2.2E-03	8.6E-03	1.4E-03	1.3E-03	8.0E-04	5.3E-04
Knitting	9.9E-03	2.4E-03	1.4E-02	5.5E-03	3.0E-03	9.5E-03	1.2E-03	1.2E-03	8.6E-04	3.6E-04
Wearing apparel	3.5E-02	3.2E-03	1.5E-02	2.3E-03	2.3E-03	8.0E-03	1.6E-03	1.0E-03	9.5E-04	4.0E-04
Other made-up textile products	1.6E-02	2.3E-03	8.3E-03	1.9E-03	4.4E-03	9.9E-03	1.6E-03	1.0E-03	7.2E-04	4.2E-04
Leather and leather products	2.7E-02	2.2E-03	6.8E-02	3.2E-03	2.6E-03	8.0E-03	2.5E-03	1.0E-03	6.0E-04	5.6E-04
Timber	8.6E-02	2.8E-03	1.2E-02	3.2E-02	4.2E-03	2.0E-02	5.1E-03	1.9E-03	7.7E-04	4.1E-04
Wooden furniture	6.5E-02	3.0E-03	5.3E-02	3.4E-03	3.2E-03	1.5E-02	3.3E-03	1.6E-03	1.1E-03	7.3E-04
Other wooden products	2.8E-02	3.7E-03	5.9E-02	4.8E-03	6.0E-03	1.7E-02	3.3E-03	1.8E-03	7.4E-04	4.6E-04
Pulp and paper	8.3E-03	2.6E-03	2.0E-02	2.3E-03	2.6E-03	1.6E-02	1.7E-03	1.1E-03	7.4E-04	3.2E-04
Printing and publishing	2.1E-02	2.3E-03	1.3E-02	8.1E-04	3.2E-03	1.5E-02	1.1E-03	5.9E-04	3.5E-04	2.2E-04
Synthetic resins and fiber	2.1E-03	9.1E-04	1.0E-02	1.3E-03	1.4E-03	1.8E-02	1.6E-03	1.3E-03	7.5E-04	2.9E-04
Basic industrial chemicals	3.8E-03	1.5E-03	5.9E-03	1.5E-03	1.4E-03	2.0E-02	1.4E-03	1.4E-03	8.6E-04	2.6E-04
Chemical fertilizers and pesticides	2.8E-03	1.6E-03	4.8E-03	9.3E-03	3.7E-03	2.3E-02	2.2E-03	2.1E-03	7.2E-04	2.2E-04
Drugs and medicine	1.2E-02	2.2E-03	6.1E-03	9.5E-04	2.2E-03	1.7E-02	9.7E-04	7.2E-04	3.2E-04	1.2E-04
Other chemical products	8.9E-03	1.9E-03	8.6E-03	1.1E-03	2.2E-03	1.7E-02	1.3E-03	1.0E-03	5.9E-04	2.8E-04
Refined petroleum and its products	7.4E-04	9.3E-04	1.8E-03	1.8E-03	3.3E-04	8.2E-03	1.4E-03	1.3E-03	8.8E-04	1.8E-04
Plastic products	9.6E-03	2.3E-03	1.4E-02	1.1E-03	3.8E-03	1.8E-02	1.4E-03	8.8E-04	6.9E-04	3.7E-04
Tires and tubes	6.9E-03	2.9E-03	7.2E-03	1.2E-02	5.7E-03	1.8E-02	8.7E-04	1.3E-03	8.5E-04	5.5E-04
Other rubber products	9.4E-03	3.4E-03	1.6E-02	1.4E-03	4.9E-03	1.6E-02	1.3E-03	1.0E-03	5.5E-04	4.5E-04
Cement and cement products	1.1E-02	2.2E-03	6.4E-03	3.6E-03	2.3E-03	1.5E-02	1.8E-03	1.1E-03	4.0E-04	4.4E-04
Glass and glass products	7.8E-03	2.1E-03	1.2E-02	1.4E-03	2.1E-03	1.4E-02	2.4E-03	1.0E-03	4.7E-04	4.1E-04
Other non-metallic mineral products	3.4E-02	3.0E-03	2.0E-02	2.7E-03	2.5E-03	1.4E-02	2.9E-03	1.2E-03	5.8E-04	3.5E-04
Iron and steel	8.2E-03	1.5E-03	1.2E-02	2.2E-03	2.8E-03	1.2E-02	1.7E-03	1.4E-03	5.0E-04	3.8E-04
Non-ferrous metal	5.6E-03	2.4E-03	7.2E-03	2.9E-03	4.1E-03	1.2E-02	2.1E-03	2.6E-03	1.4E-03	4.7E-04
Metal products	6.5E-03	2.6E-03	1.4E-02	1.8E-03	7.2E-03	9.2E-03	1.5E-03	1.0E-03	4.9E-04	4.1E-04

Table C-7. (Continue)

Sector	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Boilers, Engines and turbines	3.9E-03	2.2E-03	1.0E-02	1.6E-03	5.2E-03	8.3E-03	1.2E-03	8.5E-04	4.5E-04	3.9E-04
General machinery	4.1E-03	2.3E-03	6.8E-03	1.3E-03	3.5E-03	8.8E-03	1.6E-03	8.7E-04	5.1E-04	3.1E-04
Metal working machinery	5.7E-03	2.5E-03	9.2E-03	1.4E-03	5.3E-03	8.3E-03	1.5E-03	7.3E-04	3.8E-04	3.6E-04
Specialaized machinery	3.4E-03	2.0E-03	1.1E-02	1.2E-03	6.2E-03	8.3E-03	1.4E-03	8.1E-04	4.4E-04	3.8E-04
Heavy Electrical equipment	5.2E-03	2.8E-03	2.8E-03	2.0E-03	5.2E-03	9.2E-03	1.6E-03	1.0E-03	5.8E-04	3.8E-04
Television sets, radios,audios and communication equipment	7.7E-03	2.3E-03	6.4E-03	2.8E-03	2.5E-03	7.0E-03	1.6E-03	1.0E-03	6.4E-04	4.4E-04
Electronic computing equipment	7.1E-03	2.1E-03	2.2E-03	2.2E-03	1.9E-03	7.1E-03	1.7E-03	1.4E-03	6.8E-04	6.7E-04
Semiconductors and integrated circuits	6.5E-03	2.3E-03	3.2E-03	1.7E-03	2.8E-03	7.3E-03	1.2E-03	8.6E-04	4.9E-04	2.4E-04
Other electronics and electronic products	6.5E-03	2.0E-03	2.0E-03	1.9E-03	2.0E-03	9.0E-03	1.3E-03	9.0E-04	6.4E-04	3.2E-04
Household electrical equipment	1.8E-02	2.0E-03	4.6E-03	2.7E-03	3.6E-03	9.7E-03	1.1E-03	9.5E-04	6.3E-04	3.6E-04
Lighting fixtures, batteries, wiring and others	5.9E-03	1.7E-03	2.6E-03	1.7E-03	1.9E-03	1.1E-02	2.2E-03	1.0E-03	6.5E-04	3.9E-04
Motor vehicles	4.1E-03	2.3E-03	7.6E-03	1.2E-03	2.0E-03	8.6E-03	9.3E-04	8.5E-04	4.5E-04	3.6E-04
Motor cycles	2.7E-03	3.1E-03	3.9E-03	3.2E-03	2.4E-03	7.8E-03	1.1E-03	1.1E-03	4.4E-04	5.3E-04
Shipbuilding	1.3E-02	1.9E-03	1.3E-02	1.1E-03	2.1E-03	7.8E-03	1.3E-03	1.2E-03	4.0E-04	4.8E-04
Other transport equipment	4.7E-03	1.1E-03	2.3E-03	3.1E-04	1.7E-03	7.8E-03	1.1E-03	1.1E-03	4.0E-04	3.2E-04
Precision machines	5.4E-03	1.9E-03	1.0E-03	9.5E-04	1.4E-03	7.6E-03	1.2E-03	7.6E-04	4.4E-04	2.7E-04
Other manufacturing products	1.0E-02	1.8E-03	4.3E-02	2.3E-03	2.5E-03	8.6E-03	1.5E-03	1.0E-03	5.4E-04	3.0E-04
Electricity and gas	3.0E-03	9.3E-04	2.3E-03	6.4E-04	5.4E-04	1.8E-02	3.1E-03	1.7E-03	5.1E-04	1.3E-04
Water supply	4.4E-03	9.9E-04	4.5E-03	5.6E-03	1.1E-03	1.3E-02	3.8E-04	3.3E-04	2.1E-04	9.8E-05
Building construction	3.9E-02	3.2E-03	1.9E-02	1.5E-03	8.0E-03	1.2E-02	2.3E-03	8.1E-04	5.9E-04	4.2E-04
Other construction	1.6E-02	2.1E-03	5.5E-03	1.2E-03	7.5E-03	1.2E-02	2.0E-03	7.7E-04	4.4E-04	2.4E-04
Wholesale and retail trade	5.3E-03	2.1E-03	1.8E-02	4.4E-04	2.0E-03	6.0E-03	4.6E-04	5.8E-04	1.8E-04	2.3E-04
Transportation	1.5E-02	1.7E-03	3.1E-02	5.3E-04	1.3E-03	9.5E-03	8.3E-04	7.6E-04	3.5E-04	3.1E-04
Telephone and telecommunication	2.0E-03	5.2E-04	3.3E-03	4.9E-04	6.7E-04	5.7E-03	2.7E-04	3.6E-04	2.0E-04	1.6E-04
Finance and insurance	3.0E-03	5.5E-04	3.1E-03	3.9E-04	5.9E-04	3.0E-03	1.3E-04	1.1E-04	9.7E-05	5.8E-05
Real estate	4.5E-03	1.3E-03	1.6E-03	4.9E-04	1.4E-03	2.3E-03	9.6E-05	1.4E-04	4.5E-05	6.0E-05
Education and research	1.3E-02	1.9E-03	4.0E-03	4.7E-04	9.3E-04	5.2E-03	4.0E-04	2.5E-04	1.7E-04	1.4E-04
Medical and health service	7.8E-03	2.2E-03	7.4E-03	5.5E-04	3.4E-03	9.4E-03	3.8E-04	3.6E-04	2.1E-04	2.2E-04
Restraunts	6.0E-03	2.5E-03	1.6E-02	9.4E-04	3.8E-03	5.2E-03	1.1E-03	7.8E-04	3.1E-04	2.5E-04
Hotel	6.2E-03	1.2E-03	1.6E-02	1.2E-03	4.2E-03	5.9E-03	6.5E-04	2.9E-04	2.4E-04	3.2E-04
Other services	8.7E-03	1.1E-03	5.4E-03	7.7E-04	2.6E-03	6.8E-03	3.2E-04	3.2E-04	1.7E-04	1.3E-04
Public administration	1.3E-02	2.1E-03	9.3E-03	6.8E-04	1.8E-03	5.9E-03	3.3E-04	3.0E-04	1.4E-04	1.6E-04
Unclassified	3.9E-03	1.2E-03	0.0E+00	0.0E+00	3.0E-03	7.8E-03	4.1E-04	9.4E-04	1.9E-04	4.6E-04
AVG	**1.2E-02**	**2.6E-03**	**1.2E-02**	**2.2E-03**	**3.6E-03**	**1.1E-02**	**1.6E-03**	**1.1E-03**	**5.2E-04**	**3.2E-04**
SD	**1.5E-02**	**2.2E-03**	**1.3E-02**	**4.0E-03**	**2.6E-03**	**6.3E-03**	**1.7E-03**	**7.9E-04**	**2.8E-04**	**1.5E-04**