

## 論文の内容の要旨

論文題目 Comprehensive Material Flow Analysis for Sustainable Resource Management of Developing Economies

(発展途上国経済における持続可能な資源利用のための包括的マテリアルフロー分析)

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The global warming and climate change are real and have become a threat to all life on the earth. The natural resource is currently extracted and served greedy human-consumers with unprecedented rate and if the trend keeps rising or even remains constant with a current rate, there would not be the remaining virgin resource for coming generations. Scientists, policymakers, inventors, entrepreneurs, thinkers, global citizens, all are finding solutions and making progress to combat climate change and looking toward sustainable development. With the current population growth, expanding of urbanization, and industrialization, these challenges are tickling the global movement seeking sustainable development pathways.

To establish the ideal sustainable development pathways, the understanding of sustainable resource management is crucial. Industrial Ecology (IE) is the multi-disciplinary field that has provided analytical frameworks and indicators to support sustainability for several decades. Material Flow Analysis (MFA) is the important branch in IE that providing the knowledge of the socioeconomic systems in physical dimensions. It has been used as the high-level policy indicators in European countries, Japan, China, and now also integrated into the benchmark indicators of Sustainable Development Goals (SDGs). In this dissertation, Economy-Wide Material Flow Analysis (EW-MFA) is conducted for the case studies of developing economies. The Eurostat's EW-MFA guidelines are used as the main

analytical framework; however, it is designed with the experiences in developed countries. The applicability of the guideline to developing countries was checked, and the needed improvements for the estimation approaches were proposed specifically for developing countries.

In Chapter 1, the general background of the dissertation was discussed. The contents from this chapter include the current global environmental challenges, the principle theory of industrial ecology as the analytical framework providing the information to support sustainability. The motivations of the current research were provided which lead to the objectives of this study.

Chapter 2 presents the systematic literature review of the evolution of MFA in ASEAN's Industrial Ecology Community by using the integrated approach of Social Network Analysis and Text-mining. The methodology applied in this chapter was useful to provide a better understanding of scientific mapping. In parallel, the results pinpointed the popular research area in IE, as well as providing the discussion for the potential further research topics in ASEAN countries. The lack of MFA studies in the region was confirmed.

Chapter 3 presents the main methodology of this dissertation. It starts with the introduction of the core framework, Eurostat's EW-MFA compilation guideline. Based on the guideline, the classification of indicators and material categories were organized. The potential data sources, based on the suggestions of the guideline and author's experiences, for compiling EW-MFA were listed. Based on the limitations of the direct implementation of Eurostat's guideline to the case study of developing countries, I suggested several improvements for estimation approaches of the data that missing in the official statistics. The approaches for handling the uncertainty of EW-MFA results were also demonstrated.

Chapter 4 is the implementation of the methodological improvements in the previous chapter. The comprehensive EW-MFA (full mass balancing EW-MFA) was conducted for the case study of Lao PDR. The results granted insight into understanding of physical dimensions of Lao PDR's socioeconomic system. This was the first time that the comprehensive EW-MFA was conducted based on the local knowledge and national statistical data, with minor support from international databases to fill the data gaps. I also showed how the results from this study improved by comparing to the empirical data from UNEP International Resource Panel's database (<http://www.resourcepanel.org/global->

[material-flows-database](#)). The discussion on whether to use material flow indicators based on the direct material flow basis or based on raw material equivalent basis was briefly discussed.

In Chapter 5, another case study of developing country, Bangladesh, was included to show how the improved framework and the estimation approaches proposed in this dissertation could be implemented to provide more realistic data for other developing countries. The analysis in this chapter focused only on the main indicators of EW-MFA, including Domestic Extraction account (DE), Trades account (Imports and Exports), and derived indicators from EW-MFA framework such as Domestic Material Consumption (DMC), and Physical Trades Balance (PTB). Resource efficiency indicators, namely Resource Productivity and Resource Intensity were also included. To validate how the accounting is improved, the result was once again compared to the UNEP International Resource Panel's database.

Resource efficiency, which is the fundamental concept of sustainable resource management, was discussed in Chapter 6. Extended the results of the comprehensive EW-MFA of Lao PDR, resource efficiency analysis was conducted. The general concepts of resource efficiency and some examples of implementation in sustainable resource management policy designs were discussed at the beginning of the chapter. Resource efficiency indicators of Lao PDR, namely resource productivity, resource intensity, and emission intensity, were calculated. As Lao PDR is currently in the beginning of infrastructure development period, the analysis shows that the resource efficiency of Lao PDR is decreasing. The IPAT (Impact = Population \* Affluence \* Technology) equation was used to explore the driving forces of resource consumption in Lao PDR in different time period which chosen based on the time interval of the Five-Year National Socio-Economic Development Plan. The analysis showed that throughout all periods, population and affluence contributed to increasing domestic material consumption with affluence (growth in per-capita GDP) being the most important factor. Based on the resource efficiency indicators, the policy implication for Lao PDR was discussed.

Chapter 7 shows how the EW-MFA data could be extended by integrating the MISO model (Material Input, Stocks and Output), developed by Krausmann et al. (2017), to provide the premature insight of the material stocks which provide services for society such as shelter,

mobility, communication, and could be considered as human well-being measurement matrix. The results showed that almost all the stocks-building materials (except timber) have been exponentially increasing since the beginning period of study. At the beginning of the studied period, the growth pattern of total stocks per capita of Lao PDR was following other developing countries, but within the last decade, it already outpaced the level of some other developing countries in the rest of the world. Comparing to the average level of global stocks per capita in 2010, with the current rate of accumulation, the level of stocks per capita of Lao PDR is likely to surpass the global level soon. However, when compared to other industrial countries, the level of stocks per capita of Lao PDR is still relatively low. This is a very good opportunity for the country to leapfrogging the resource use to optimal saturation level by increasing resource efficiency through system-wide policy design, technology advancement, and innovations.

Chapter 8 is the conclusions and recommendations of the dissertation. The dissertation was summarized including the main messages from the dissertation's findings. The contribution to the scholarly communities in terms methodological improvement was summarized here. The suggestions for the policy implications of the research findings were provided. The recommendations for practitioner and researchers in terms of the future works to improve the EW-MFA in developing countries were given. Finally, by providing the recommendations for sustainable resource management for Lao PDR, the usefulness of the improved EW-MFA was confirmed, and the main objectives of this dissertation were achieved.