Improving the knowledge base on material flow analysis for Asian developing countries: A Case Study of Lao PDR

For submission to Resources, Conservation & Recycling

Xaysackda Vilaysouk[1,2,*], Heinz Schandl[2,3] and Shinsuke Murakami[1]

[1] Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-8656, Japan

*Corresponding author e-mail: xaysackda@g.ecc.u-tokyo.ac.jp

[2] CSIRO, Black Mountain Science and Innovation Park, Clunies Ross Street, Acton, ACT 2601, Canberra, Australia

[3] Australian National University, Fenner School for Environment and Society, Acton, ACT 2601, Canberra, Australia

Abstract

National material flow accounts have reached maturity over the past decade. Many countries, including the European Community and Japan, now report material flows as part of their national statistical reporting. Global and country by country data has been prepared by the International Resource Panel of United Nations Environment, filling a reporting gap for many countries of the global South. In this research we establish, for the first time, a national material flow account for a low-income country – Lao People's Democratic Republic – which is solely based on national statistical data from the Lao PDR and in-depth information on the specifics of a low-income, Southeast Asian economy. We develop accounts for domestic extraction and trade for the period 1988 to 2015. In contrast to existing accounts based on international data sources, our calculation of material flows in Lao PDR includes detailed information about the mining sector, agriculture (including livestock fodder and subsistence economy), forestry and timber harvest which are not available from the international data. The results indicate that domestic material extraction increased ten-fold from 11.3 million tonnes to 120.1 million tonnes, driven by the extraction of natural resources for infrastructure development and primary resource export-oriented sectors. We also engaged with the Lao PDR National Statistical Office to improve trade accounts and have added sensitivity analysis to our accounts. This allows us to test the robustness and credibility of the international datasets that are filling the gap in the absence of national accounts in many developing countries in Asia and beyond.

Keywords: Economy-wide material flow analysis (EW-MFA); uncertainty; developing countries; industrial ecology; Lao PDR; environmental policy

Introduction

Material flow analysis (MFA) is an analytical framework used to assess domestic extraction and trade of materials and the disposal of waste and emissions by a national economy in a way that is compatible with economic accounting and the System of Integrated Environmental and Economic Accounting (SEEA) (Ayres and Simonis, 1994). The accounting framework has reached maturity in the past couple of decades (Fischer-Kowalski et al., 2011) and has become part of official statistical accounting in many countries, most notably in the European Union (EU) and Japan. In these countries MFA has become a core component of environmental accounting and serves as a basis for evidence-based policy making. The Japanese government's Sound Material Cycle Society high level policy objective, for instance, uses three indicators derived from material flow accounts (Takiguchi and Takemoto, 2008) to support the implementation of a 3R policy agenda. Similarly, in the EU, resource productivity is used as the lead indicator, along with other MFA indicators, in the EU Resource Efficiency Scoreboard to measure progress toward increased resource efficiency of individual Member States and the European Union as a whole (European Commission, 2017).

Resource efficiency has become an important objective of the G7 major economies, which launched a new initiative in Germany in 2016 that requires the integration of resource management and economic policy in one coherent framework (Bringezu et al., 2016). In the G7 Toyama Environment Ministers' Meeting held at Toyama, Japan in May 2016, the Toyama Framework on Material Cycles reaffirmed the G7's active leadership in environmental policies with the common vision of enhancing resource efficiency and promoting the 3Rs (Ministry of the Environment Government of Japan, 2016). Implementation of the new Sustainable Development Goals (SDGs) and the monitoring of progress toward goals and targets that address resource productivity, sustainable resource management and resource efficiency at industry level are especially important for low-income countries that have large development needs and require timely and affordable natural resources. Despite this essential need for the materials that will underpin human development and prosperity, many low-income countries use their domestic natural resources to generate export revenues, i.e. their resources benefit people in other parts of the world, mostly in high income countries (Wiedmann et al., 2015).

Information needs for low-income countries are substantial but the institutional capacity, financial resources and human capital for statistical reporting are often lacking (UNEP, 2013). Nevertheless, there are a number of examples of material flow accounts for developing countries and regions that have been prepared by academics, often with support from the United Nations (UNEP, 2011).

Several studies have employed standard Eurostat methodology for national material flow accounting and hence provide datasets and indicators that are comparable across countries. MFA datasets now exist for the Philippines (Martinico-Perez et al., 2016), India (Singh et al., 2012), China (Wang et al., 2012), and Asia and the Pacific (Schandl and West, 2010), as well as for the global level (UNEP, 2016). However, many of these studies sourced their data from international databases and utilized international parameters, not giving due justice to special characteristics of low-income economies, such as their considerable share of subsistence economic activities, underreporting and grey economic activities, and particular features of their agricultural and livestock systems.

In this study for the Lao People's Democratic Republic (Lao PDR) we chose a different strategy for establishing material flow accounts, relying as much as possible on nationally available data. Lao PDR is a land-locked country located in the center of the Indochinese peninsula, with a small population of 6.4 million and a very low population density of 27 persons per km^2 (Lao Statistics Bureau, 2015b). Over the past decade the Lao economy has grown strongly, with the annual Gross Domestic Product (GDP) growth rate consistently over 7%. Per-capita GDP increased from 324 US$ to 1,818 US$ between 2000 and 2015

(World Bank, 2017a) but Lao PDR is still considered to be one of the least developed countries in Asia. Lao PDR is rich in natural resources including metal ores, fossil fuels, timber, non-timber forest products and hydroelectricity. The structural composition of the Lao economy has shifted from agriculture to industry and services since the economic liberalization of 1986. The proportion of GDP generated by the agriculture sector shrank from 52.1% to 23.8% over the period 2000 to 2015 (Lao Statistics Bureau, 2015a).

The United Nations Environment Programme has invested in material flow accounts since 2011 (Schandl et al., 2010; UNEP, 2011). This has underpinned a number of reports which provide MFA datasets for all countries in Southeast Asia, including Lao PDR (UNEP, 2015). We use the international dataset as a benchmark for the current study and aim to show how the use of national data and expertise leads to different results in MFA accounts. To put it another way, we consider how accurate material flow accounting based on international data sources is for low-income countries. The latest methods guide from Eurostat (2013) suggests that using domestic statistical data and country-based parameters to compile a national MFA account could deliver more realistic results.

Due to steady development in Lao PDR over the past decade, we believe that the structure and level of resource use will have changed. This is a good opportunity for Lao PDR to update its industrial ecology knowledge, and could provide information for policy makers to integrate results of our study into the national development strategy. Lao PDR has only just started to build up significant infrastructure to support economic development. The need to catch up with its neighbors in urbanization and industrialization and to improve the material standard of living of its people will require a massive amount of materials. Appropriate policies to support sustainable resource use and resource efficiency are necessary to guide Lao PDR’s development planning. Historical trends on material extraction and consumption patterns are key information for policy makers. Integrating sustainable resource use into economic development could enable Lao PDR to identify strategies to increase the country's competitiveness, and achieve the aspired economic benefits at lower environmental cost. With this study we wish to build an evidence base for resource policy in Lao PDR. The objectives of this study are:

- to provide insight into resource use in relation to economic development in Lao PDR by establishing robust data and indicators for material extraction and trade
- to compare national MFA data for Lao PDR with previous studies and selected countries in the region
- to improve the methodology for material flow accounting in low-income countries
- to discuss the results with respect to their importance for resource management policy and the Sustainable Development Goals.

Methodology and data sources

Economy-wide material flow analysis (EW-MFA) is an analytical framework to provide information on natural resource use for a national economy. The European Statistical Office (Eurostat) played an important role in the development of the EW-MFA methodological guidelines. Eurostat's EW-MFA compilation guidelines have been widely used to compile EW-MFA at global, regional and national scales. In this study, the latest Eurostat EW-MFA guidelines (Eurostat, 2013) will be used as the main framework to discover the resource use patterns of Lao PDR for the years 1988 to 2015. To estimate some materials that are missing in the official statistical reports, the standard approaches suggested by Eurostat will be used along with adaption to appropriate country-based coefficients. The materials were distinguished into 33 types and aggregated into four main material categories including biomass, metal ores, non-metallic minerals, and fossil energy materials. We accounted for the main EW-MFA indicators such as Domestic Extraction: DE, Imports: IMP, Exports: EXP, Physical Trade Balance: PTB and Domestic Material Consumption: DMC.

Domestic Extraction

<u>Biomass</u>: Data for the dataset on domestic extraction of biomass was obtained from the Center for Agricultural Statistics of the Department of Planning and Cooperation, Ministry of Agriculture and Forestry of Lao government through an official data request letter; it covers the majority of crops in Lao PDR (Ministry of Agriculture and Forestry of Lao PDR, 2015a). The sub-category of crops has been aggregated from 34 different crops recorded in national agricultural statistics. Crop residues are not reported in agricultural statistics and were estimated for key crops including rice, maize, soybeans, and sugar cane. The estimates were based on harvest factors and recovery rates provided by Eurostat (2013) and were adjusted for local conditions. In Lao PDR, fodder crops are mainly used to feed pigs and poultry and were calculated using a demand-side approach. Total demand for fodder crops was estimated based on the number of pigs and poultry, and feeding factors provided by the Lao government (Ministry of Agriculture and Forestry of Lao PDR, 2015b).

Animal feed recorded in the industrial products statistics was deducted from total fodder demand to estimate fodder crops. Grazed biomass was estimated in a similar fashion. Feed demand for livestock was separately estimated for four different livestock categories including buffalo, cattle, goats and sheep based on the number of livestock in the agriculture dataset and feeding factors provided by the Department of Livestock and Fisheries, MAF (Ministry of Agriculture and Forestry of Lao PDR, 2015b, c). Following Eurostat (2013), estimated fodder crops and grazed biomass were converted to air dry weight, i.e. 15% moisture content.

Due to the lack of data on wood production in Lao official statistics, the Food and Agriculture Organization (FAO, 2017) database was used to fill the gaps. Based on the FAO wood and timber

This is peer reviewed version of the following article: [Vilaysouk, X., H. Schandl, and S. Murakami. 2017. Improving the knowledge base on material flow analysis for Asian developing countries: A case study of Lao PDR. Resources, Conservation and Recycling 127: 179-189.], which has been published in final form at [https://doi.org/10.1016/j.resconrec.2017.09.006]. This article may be used for non-commercial purposes in accordance with publisher Terms and Conditions for Use of Self-Archived Versions.

production figures, density data for different timber species provided in Eurostat (2013) was used to convert volumes into physical weight at 15% moisture content. Firewood data was crosschecked with the Lao PDR household survey. Wild fish catch and animal hunting are not reported in agricultural statistics. Thus, we estimated the wild fish catch based on average fish catch per capita of Lao wetlands reported in Gerrard (2004) and total rural population from the latest census (Lao Statistics Bureau, 2015b). For animal hunting, we assumed the amount to be negligible compared to other materials and did not include it in the accounting.

For low-income countries, the share of biomass used in subsistence activities in agriculture and forestry is significant and includes crops, firewood, non-timber forest products, wild fish catch and animal hunting. It is, however, insufficiently covered in official statistics. While estimates for crops and firewood existed in official accounts, additional assumptions were required for other subsistence products to the extent possible.

Metal ores: In material flow accounting metals are commonly accounted for as gross ores run of mine; however, the dataset of minerals production that was provided by the Department of Mines during a data collection trip reports different stages of concentration of ores (Ministry of Energy and Mines of Lao PDR, 2015b). The dataset contains nine types of metal products, 15 types of non-metallic mineral products, and three types of fossil energy carriers. The extraction of metals is reported either as ore, concentrate or metal content. This often requires recalculation of the ore that was required for the amount of metal reported. As much as possible, we rely on company reporting for ore grades. One source for additional insight into ore grades was the S&P Global Market Intelligence database (SNL), which is a platform that provides financial news, data and analysis for financial services, real estate, energy, media, communication and the metal and mining sectors. The SNL database includes detailed information about the Lao mining sector such as information on exploration budgets, resources and reserves, as well as production information. In this study we used total ore processed data for individual mines in Lao PDR from the SNL database (SNL, 2016) to compile domestic extraction data for copper ores, gold ores and coupled products. From the total processed ore data, we allocate the coupled products using "Aliquot allocation of ore tonnages" based on long-term average prices of the metal (Eurostat, 2013). For other metals, for which the amount is small, we used concentrate and metal content products and average ore grades from Eurostat to calculate the gross ores.

Non-metallic minerals: The Lao mining data (Ministry of Energy and Mines of Lao PDR, 2015b) includes information for chalk and dolomite, chemicals and fertilizers, salt, gypsum, and barite. Bulk materials such as sand and gravel, clays and kaolin, and limestone for cement production are not reported. Clay and kaolin used for the production of bricks was derived from brick production accounts reported in the industrial products dataset (Ministry of Industry and Commerce of Lao PDR, 2015b). The total raw material of clay and kaolin required to produce the bricks was calculated using the material intensity of brick provided in Miatto et al. (2016) ($\lambda_{brick} = 1.16$). Finally, the total required materials of clay and kaolin were converted from volume to physical weight ($\rho_{bricks} = 2{,}403\ kg/m^3$) using the material density provided in the SIMETRIC database (SIMETRIC, 2017).

For aggregate materials, we distinguish sand and gravel used for construction and aggregate used for road base construction and maintenance. We use the apparent consumption of cement to calculate sand and gravel extraction. The total sand and gravel required to produce concrete based on cement consumption was calculated using concrete mixing ratios ($C_{(i)}$: cement (kg) / $S_{(i)}$: sand (liter) / $G_{(i)}$: gravel (liter)). The standard mixing ratio for Lao PDR was provided by the Department of Housing, Ministry of Public Works and Transportation of Lao PDR. There are four standard mixing ratios (Concr.1: 150/400/800; Concr.2: 250/400/800/; Concr.3: 300/400/800; Concr.4: 350/400/800) classified by the strength of the concrete (the higher the cement ratio, the higher the strength of the concrete). We calculated the four possible mixing ratios and the shares of Concr.1: 1/2.67/5.33 to Concr.4: 1/1.14/2.29 in Lao concrete consumption. Then the intensity of sand and gravel used in Lao PDR from cement consumption was calculated as:

$$\lambda_{concr.Lao(i)} = \frac{S_{(i)}}{C_{(i)}} * \rho_{sand} + \frac{G_{(i)}}{C_{(i)}} * \rho_{gravel} \qquad (1)$$

Where $\lambda_{concr.Lao(i)}$ is the intensity of concrete, $S_{(i)}$ is the ratio of sand, $C_{(i)}$ is the ratio of cement, $G_{(i)}$ is the ratio of gravel, and ρ_{sand} and ρ_{gravel} are the density of sand and gravel, respectively.

From the equation above, the intensity of concrete resulted in a range between $\lambda_{concr.Lao(4)} = 5.77$ to $\lambda_{concr.Lao(1)} = 13.46$. High strength concrete (Concr.3 and Concr.4) is mainly used for reinforced concrete, which is used for building structural elements and floors. We assume that high strength concrete Concr.4 accounted for 60% of total use, followed by Concr.3 at 30%, and low strength concrete Concr.2 and Concr.1 accounted for 5% each. The resulting material density for sand and gravel based on cement consumption for Lao PDR is 6.55 tonnes of sand and gravel ($\lambda_{concrete.Lao(aver.)} = 6.55$) per tonne of cement. This number is higher than the global average estimated by Miatto et al. (2016) ($\lambda_{concr} = 5.26$) and a default number provided by Eurostat as 6.09 which is explained by differences in mixing ratio standards and assumptions made in the estimation process.

To estimate aggregate used in road construction and maintenance, Eurostat suggests using the intensity of aggregates per length of newly built road and per existing length of road network. Another approach is to estimate aggregate use from the apparent consumption of bitumen (Krausmann et al., 2009; Miatto et al., 2016). In Lao PDR, data on bitumen consumption is not reported in the statistics and thus we relied on road data and average aggregate intensity per km of newly constructed roads or for road maintenance. The Ministry of Public Works and Transportation of Lao PDR (2015) reports statistics for public works and transportation, which include the length of different types of the road, every five years.

In-between years were calculated using statistical trends. We had to rely on the default average aggregate intensity suggested in Eurostat's guidelines to estimate the aggregate used for road construction in Lao PDR.

Fossil energy carriers: Lao PDR does not have substantial fossil fuel deposits, with the exception of coal deposits in Xayabury and Vientiane Provinces. Data for coal extraction was sourced from the Ministry of Energy and Mines of Lao PDR (2015b).

Imports and Exports

Physical trade data shows the integration of an economy into the world market for primary materials and its dependency on resources from abroad or its contribution to the global resource supply. We report direct trade flows (in tonnes) at the time when commodities cross the national boundary. Trade statistics in Lao PDR are in their infancy and a full and reliable trade account is only available for the year 2015. Additional national trade data from the Ministry of Industry and Commerce of Lao PDR covers the years 2010 to 2015 (Ministry of Industry and Commerce of Lao PDR (2015a)). To compile consistent trade accounts we needed to integrate national statistical data with information from the UN COMTRADE (2017) database. For those years where no reporting exists in Lao national statistical datasets we relied on information on bilateral trade from Lao PDR's trade partners, such as Thailand and Viet Nam, which have more reliable trade statistics. We integrated the national dataset (2010–2015) with COMTRADE data (1988–2015) which required numerous data adjustments. We are confident that we are reporting reliable physical trade numbers for Lao PDR for the first time.

Data from the Ministry of Industry and Commerce of Lao PDR (2015a) contains transaction data on imports and exports for trade values for 2010 to 2015 but reports physical trade only for 2015. We estimated the "tonne price" for all commodities individually for 2015 based on HS-code classification at the 4-digit level and applied the resulting unit prices to monetary values in other years (2010–2014) to estimate the physical weight.

This approach yields unrealistic unit prices for some commodities such as cement and crude oil because of potentially false records of total weight. This was discovered when comparing national data with COMTRADE data and such irregularities were corrected through data matching. This strategy was employed for the top 20 commodities in terms of volume, for both imports and exports, to establish adjusted unit prices for those commodities. These were used to align COMTRADE data and national trade data into one coherent time series. We also calculated the physical trade balance for imports and exports by subtracting export data from import data.

DMC and material efficiency

Domestic material consumption (DMC) or apparent consumption reports material use for a domestic territory and can hence be interpreted as a long-term waste equivalent (UNEP, 2016). DMC is calculated as DE plus imports (IMP) minus exports (EXP). The lower the integration of a country into world trade the more similar the figures for DMC and DE.

Material efficiency indicators were calculated to show the interaction of resource use and economic activity. Material efficiency can be expressed as material productivity (GDP/DMC) or material intensity (MI = DMC/GDP). In this study, we used MI to represent the material efficiency of the Lao economy. We used exchange-rate based GDP from UNSD (2017) at 2005 constant prices.

IPAT analysis for resource consumption drivers

IPAT is a simple analytical framework that helps uncover broad driving factors of environmental impact. IPAT was developed by Ehrlich and Holdren (1971) and aims to explain the impact on the environment of a process or economic activity (I) as the product of population (P), affluence (A), and technology (T). As proposed by Schandl and West (2010), I is defined as the total DMC, A as GDP per capita, and T as DMC per unit of GDP. We transformed the IPAT equation to a logarithmic form following the methodology proposed by Herendeen (1998).

Uncertainty in DE

Currently, many studies include the uncertainty of MFA results. There are several methods to assess the uncertainty of MFA. Based on the limitations of the data we have, we construct the uncertainty range of the results based on certain assumptions. We assign uncertainty to each material based on the sources of the data. The data obtained from official statistics (crops, wood, metal ores, and fossil fuels) was assumed to have uncertainty of ±10%. Estimated materials (crop residues, fodder and grazed biomass, sand and gravel) were assumed to contain higher uncertainty of ±20%. Using a simple and straightforward method of Gauss's law of error propagation, which is used to propagate the error of EW-MFA indicators in Patrício et al. (2015), the uncertainty of DE as standard deviation was obtained for all years.

Results

Domestic extraction of materials in Lao PDR

Domestic extraction of materials in Lao PDR increased from 11.3 million tonnes in 1988 to 120.1 million tonnes in 2015, a ten-fold increase in less than three decades (see Figure 1a). Initially, the domestic extraction of biomass dominated total DE at a share of almost 80%, reflecting the agricultural nature of the Lao economy. Starting in the early 1990s, non-metallic minerals, mainly aggregates for road construction, started to play a more important role in DE and consistently increased until the 2000s. Domestic extraction accelerated in 2003–2004 when the first commercial gold mine in Sepon started to operate, which resulted in a sharp increase in metal ores in total DE. In 2005, there was a notable increase in non-metallic minerals, which was caused by the coincidence of a number of very large construction activities including the start of construction of the biggest hydropower plant in Lao PDR, Nam Theun 2. This enormous hydroelectricity dam has a total installed capacity of 1,070 MW and is one of the largest in the region. Nam Theun 2 was accompanied by a number of other medium-sized hydropower projects with total capacity of more than 1,000 MW.

2005 was also the start of large-scale copper mining (Sepon Mine, Savannakhet Province). Until 2008, all material extraction, except for metal ores, grew slowly but 2005 marked the starting point of a very rapid increase in extraction of copper and gold ores destined to shore up export earnings. Throughout the period, the DE of fossil fuels was minor due to the lack of deposits of oil and natural gas. There are, however, significant coal deposits in many locations across the country with the biggest deposit being Hongsa lignite deposit located in Xayabury Province. Domestic coal was partially supplied for the cement industry and the surplus was exported. In 2015, the first Lao coal power plant, Hongsa Power in Xayabury Province with a total power output of 1,653 MW, started operation. It requires a steady input of domestic coal and will drive coal extraction. Until now, the amount of fossil extraction has remained insignificant compared to other material categories but this is going to change in the future. By 2015, non-metallic minerals accounted for almost half of DE, followed by 26% biomass, 22% metal ores, and 4% fossil fuels (see Figure 1b). This reflects massive changes in the Lao economy over the past three decades, from a purely agricultural, biomass-based economy to a growing focus on mining, energy generation and creating transport corridors between Thailand, Viet Nam and the Chinese Yunnan province.

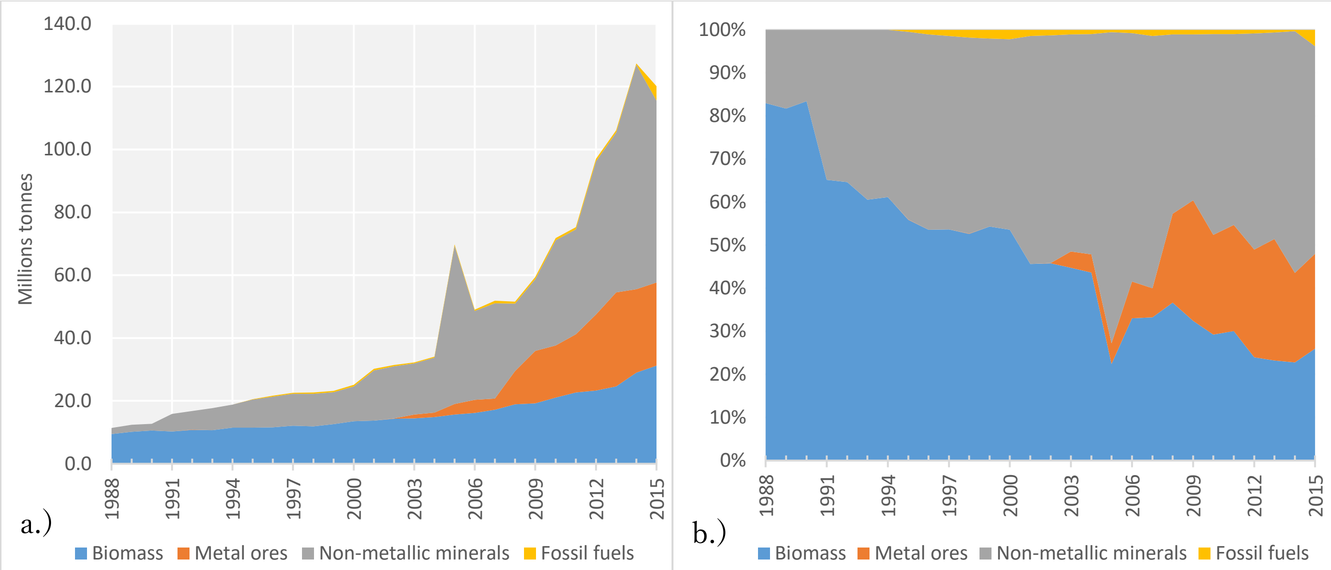

Figure 1.a. Domestic extraction by four materials categories and b. shares of total DE in percentage in 1988–2015

Table 1 shows DE by 13 sub-categories. The total average growth rate of DE was 9%. Non-ferrous metal ores experienced the most rapid growth at 45% per year, on average, but staring from a very low base in 1988. Iron ores and chemical and fertilizer minerals also increased steadily with an average yearly growth of 25% and 29%, respectively. Construction materials such as limestone and gypsum, clay and kaolin, and sand and gravel, which have the highest share in DE, increased at a slower rate of around 13% to 17% per year. Crops, important for food supply, animal feed and fiber grew at an intriguing rate of 9% per year on average which was much faster than the world average of 4% per annum. This very substantial expansion of agricultural production is testament to the ongoing transition of Lao agriculture from a smallholder subsistence system to a modern, higher input industrialized agricultural system. Fossil fuels are also seeing substantial yearly increases but future growth is expected to be much larger in light of the fuel needs of an expanding conventional power generation infrastructure.

Table 1. Domestic extraction by sub-categories, in tonnes

DE in Sub-categories	1988	1998	2008	2015	Annual Growth rate
Crops	1,475,277	2,251,159	6,293,993	13,885,152	9%
Crop residues and fodder and grazed biomass	3,878,456	5,239,760	8,034,022	10,557,586	4%

Wood	3,795,135	4,086,783	4,175,680	6,285,279	2%
Fish capture and other aquatic animals	269,413	347,093	406,254	457,096	2%
Iron	-	-	13,693	247,461	25%
Non-ferrous metal	1,097	2,379	10,587,887	26,248,442	45%
Chalk and dolomite	91,500	794,000	1,725,000	3,974,710	15%
Chemical and fertilizer minerals	-	5,500	1,000	391,748	29%
Salt	11,000	16,000	25,100	50,930	6%
Limestone and gypsum	80,000	579,948	2,013,589	5,775,030	17%
Clays and kaolin	80,436	283,115	1,408,694	3,105,213	14%
Sand and gravel	1,666,667	8,639,852	16,283,129	44,553,892	13%
Coal and other solid energy products	-	401,000	565,741	4,564,700	15%
Total	11,348,981	22,646,588	51,533,783	120,097,238	9%

Trade of materials in Lao PDR

Figure 2 shows the trends in imports and exports in physical units in Lao PDR between 1988 and 2015. These results establish, for the first time, a realistic account of physical trade for the Lao economy achieved by aligning all available information from Lao National Statistics with international, UN COMTRADE, datasets. Overall, the physical trade accounts show an increasing engagement of the Lao economy with the rest of the world. In the 1990s imports were very small at 0.1 to 0.9 million tonnes, reflecting the effects of import substitution policies. The acceleration of imports started in 2003–2004 when imports started to increase from initially one million tonnes in 2003 to 7.5 million tonnes in 2015. Total imports in 2015, however, reached only 6% of domestic material input (DMI; the sum of DE and IMP). In 2015, the main imports were construction materials (mostly cement), fossil fuels, metal products such as iron and steel bars, and semi-manufactured and finished products and animal fodder (see Figure 2a).

From the late 1980s to the late 1990s exports were dominated by timber, reaching a peak of 0.8 million tonnes in 1997. In 1997–1998, total exports from Lao PDR declined, due to economic contraction during the Asian financial crisis and diminished demand for Lao products from the country's Southeast Asian neighbors. By 2003, exports had recovered and refocused on hard coal and non-metallic minerals. Increasingly, with the production of gold and copper, metal ores have become more important in the Lao export portfolio. In 2011–2012 Lao exports experienced another slump, this time caused by sluggish global demand for primary resources in the aftermath of the global financial crisis of 2008–09 and the slow recovery of the world economy. Total exports fell from 3.1 million tonnes to 2.7 million tonnes. Since the year 2000, agricultural exports have started to shift from timber to crops. Exports of biomass from 2000 onwards were mainly led by the export of agriculture products, shifting from exports of timber to crop production (see Figure 2b). The marked increase in imports and exports during the past decade indicates that the Lao economy has become more integrated into global markets. This has also caused greater vulnerability of the economy to global resource markets and price fluctuations, which is especially problematic for countries whose exports are dominated by primary materials because of an absence of industrial infrastructure and value-adding in the country.

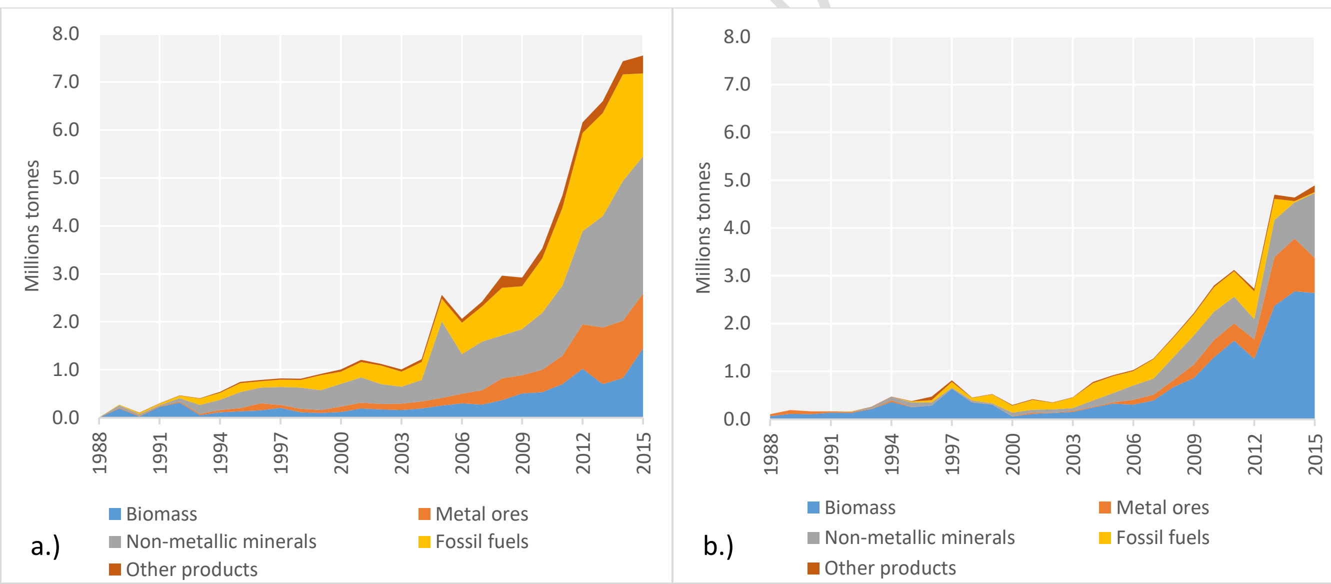

Figure 2. a. Imports by main materials categories, b. Exports by main materials categories in 1988–2015

Despite the focus on primary sectors for export, the physical trade balance (PTB) for Lao PDR, i.e. imports minus exports, has been mostly in surplus showing Lao PDR as a net importer of materials (see Figure 3a). Lao PDR has been a net importer of fossil and non-metallic minerals and exported surpluses of biomass, timber and more recently crops (Figure 3b). From 2006 to 2011, the increase in copper production, with three copper mines now in operation, meant that Lao has become a net exporter of metal ores. A continuing focus on primary industries for export may mean that the physical trade balance of Lao PDR will become negative and Lao will become a net exporter of primary materials in the not very distant future.

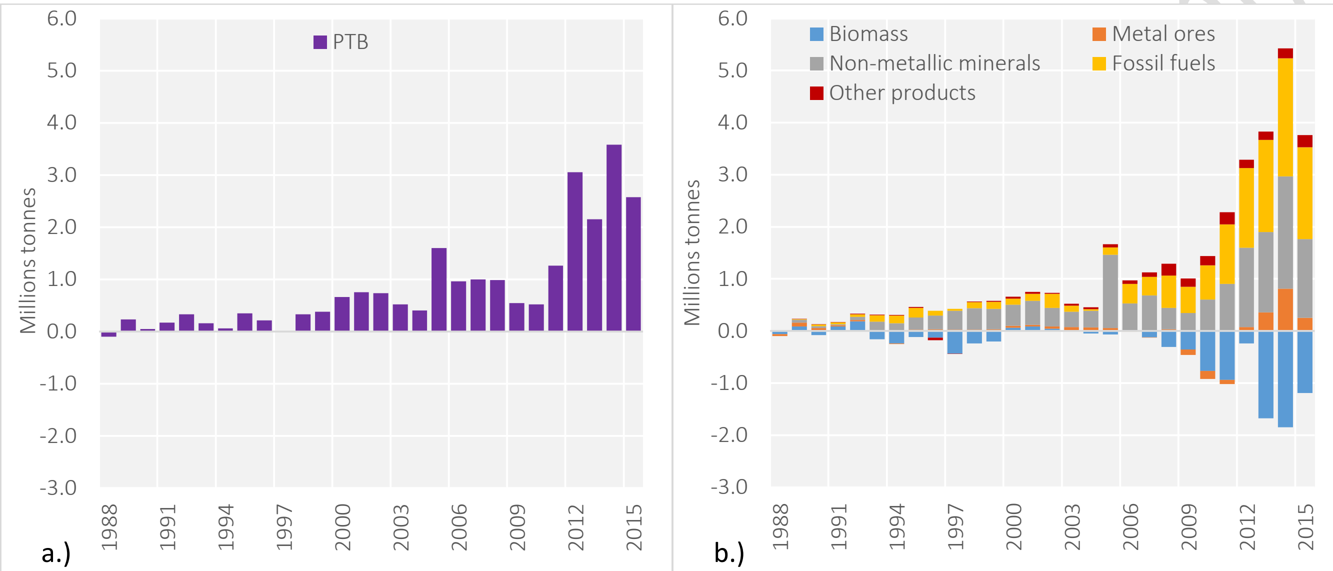

Figure 3. a. Total physical trade balance and b. Physical trade balance by main materials categories in 1988–2015

Material efficiency and metabolic rate of the Lao economy

Material efficiency is an indicator to measure the economic efficiency of resource use across a whole economy. Figure 4a shows the evolution of the material intensity of the Lao economy between 1988 and 2015. While most economies improve their material intensity as they modernize this has not been the case in Lao PDR. The material intensity of the economy almost doubled during the past three decades. It increased from an already very high level of 12.5 kg per USD in 1988 to 21.1 kg per USD in 2015 (see Figure 4a). This indicates that material use in Lao PDR has become less economically efficient throughout the whole period with a few years of insignificant efficiency improvements in between. Material intensity peaked in 2005 when a number of large hydropower construction projects started, most notably Nam Theun 2 hydropower plant, which required an enormous amount of construction materials. Overall, material use in the Lao economy has grown much faster than economic activity, i.e. GDP and increases in material extraction and use have not been benefiting the economy in terms of economic growth and increased human wellbeing.

Another important feature of the material flow analysis is the metabolic rate, which is expressed as domestic material consumption (DMC) per capita. Figure 4b shows per-capita DMC by main material categories, and a category for other products. Because trade flows are still very small, DMC is only slightly different from DE. From 1988 to 2004 per-capita DMC doubled from 2.8 to around 6 tonnes but then increased sharply to 9.8 tonnes per capita in 2009 and around 20 tonnes per capita in 2015. Overall natural resource use in Lao PDR has been transformed from a biomass-based to a metal ore and non-metallic minerals -based economy, indicated by the fast increasing DMC per capita of these materials. In 1988, the metabolic rate of non-metallic minerals in Lao PDR was at 0.5 tonnes per capita and it had increased to 8.7 tonnes per capita by 2015. Metal ores and fossil fuels also grew rapidly and increased from less than 0.1 tonnes per capita in 1988 to 4.8 tonnes per capita in 2015. Most of this growth has been related to export industries and has not resulted in large improvements in domestic infrastructure.

Per-capita DMC of biomass has grown more slowly, increasing from 2.5 tonnes per capita in 1988 to 4.4 tonnes per capita in 2015. The increase in DMC of non-metallic minerals is likely to be of benefit to the Lao economy and people as these materials are mainly used to construct buildings, roads, hydropower plants, and other infrastructure which underpin the continuous urbanization and industrialization of the country. Metal ores are a different case with a large fraction of DMC ending up as mining waste and tailings at mining sites, causing a variety of environmental issues including toxic waste and pollution and requiring long-term management.

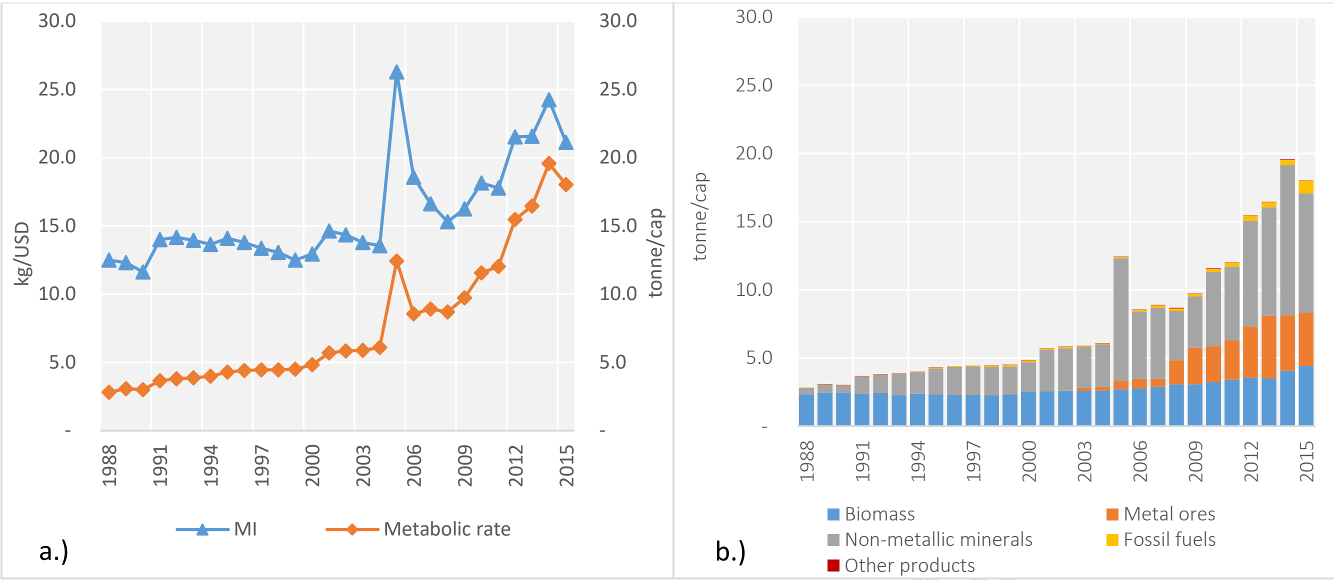

Figure 4. a. Material intensity (DMC per GDP) and metabolic rate (DMC per capita), b. Metabolic rate by main materials categories of Lao PDR in 1988–2015

Trends and drivers of material use

Figure 5a shows the long-term trends in a set of indicators including DMC, GDP and MI as well as population growth and HDI improvements. Overall, material use has grown much faster compared to economic development and improvements in technology and material intensity. Over the past three decades, DMC increased almost 12-fold, GDP about 6-fold, and as a result MI doubled. The very rapid growth in DMC, outpacing GDP, indicates the development path of the Lao economy has relied on bulk materials for infrastructure development and on export-oriented primary resource sectors. As a consequence there has not been decoupling of material use and environmental burden from affluence over the past three decades. Population and increases in human development both showed more benign growth trajectories compared to growth in resource use and the economy.

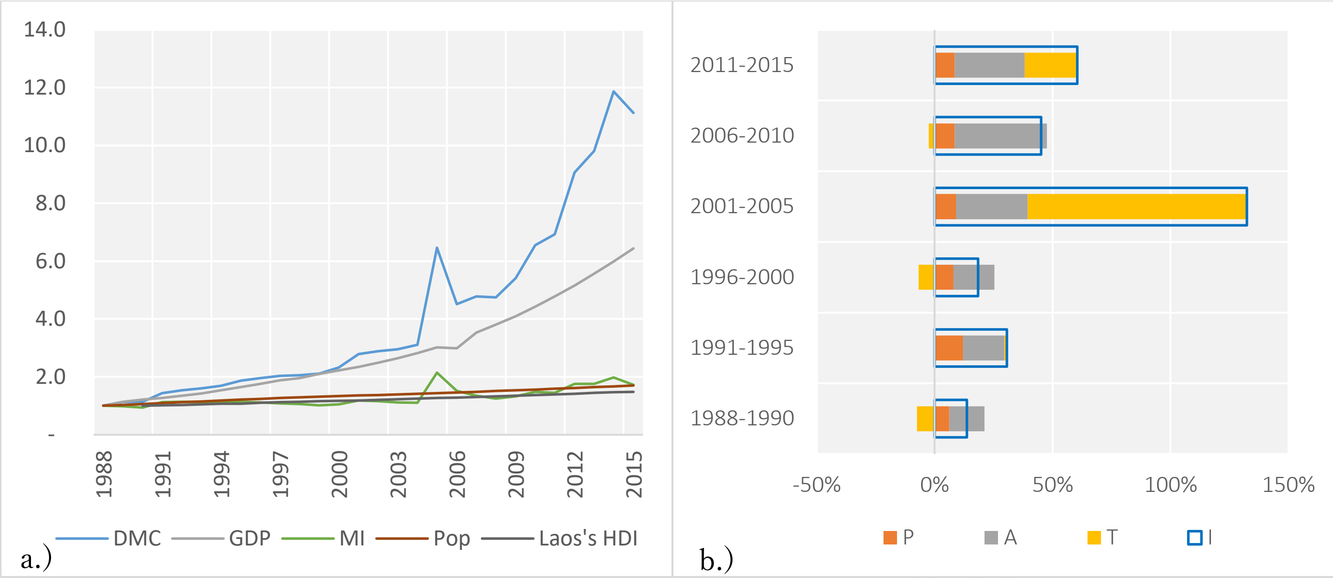

Figure 5.a. Trends in selected indicators (Index 1988 = 1), b. IPAT analysis of materials use in Lao PDR

To identify drivers for the rapid increase of DMC (I) we used the IPAT analytical framework. This shows the extent to which population growth (P), affluence (A), and technological development coefficient (T) contributed to or mitigated DMC growth. We divided the time series into six 5-year periods which corresponded to the Five-Year National Socioeconomic Development Plans of Lao PDR (NSEDP) prepared by the Ministry of Planning and Investment. Throughout all periods, population and affluence contributed to increasing domestic material consumption with affluence (growth in per-capita GDP) being the most important factor (see Figure 5b). During 1988–1990, coinciding with the 2nd NSEDP at a time when the Lao socioeconomic system was transforming from a centrally planned system to a more market based system through the introduction of the New Economic Mechanism in 1986, DMC grew by 14%, mainly driven by increases of P and A and offset by some improvement in material intensity.

From 1991 to 1995, all three factors played an important role in contributing to a 31% increase in DMC. From 1996 to 2000, P and A continued to drive total material consumption but with a small offset achieved through technological improvement. The years 2001 to 2005 signified the onset of an acceleration period of material consumption in Lao PDR with a total increase in DMC of 132%. In this period, the increase in material consumption was mainly driven by a large increase in the material intensity (T) of the economy coupled with the consistent contributions of P and A. The years 2006 to 2010 were a period of reprieve, reflecting global economic conditions, but from 2011 to 2015 the Lao economy was back on a material growth trajectory of 61% of DMC. The increase was fueled by population and consumption growth and further industrialization, with the transition from traditional to modern society i.e. from a biomass-based agricultural economy to a minerals-based industrial and urban economy, leading to higher overall material intensity of the economy.

This research is the first study of material flows in Lao PDR based on nationally available data. It adds considerable value to the evidence base on Lao resource use which, until now, had to rely on international data, and shows the comparison of total DE between our results and the data from UN Environment's database (UN Environment, 2017). When we compare the results for DE from this new study to the accounts provided by UN Environment, we see significant differences, especially for metal ores and non-metallic minerals but to a lesser extent also for biomass (see Figure 6b). The significant differences between our results and those of UN Environment are due to different assumptions made for the estimation of non-metallic minerals and the data used to account for metal ores. In our study, it is the first time that sand and gravel for construction have been estimated based on cement consumption and the newly developed intensity of concrete in Lao PDR. We also included an estimation of aggregates used for road construction based on the additional length of road network in the country and the average material intensity for road construction. For metals, we directly used the total amount of ores processed rather than an estimation of gross ores using ore grades and metal products.

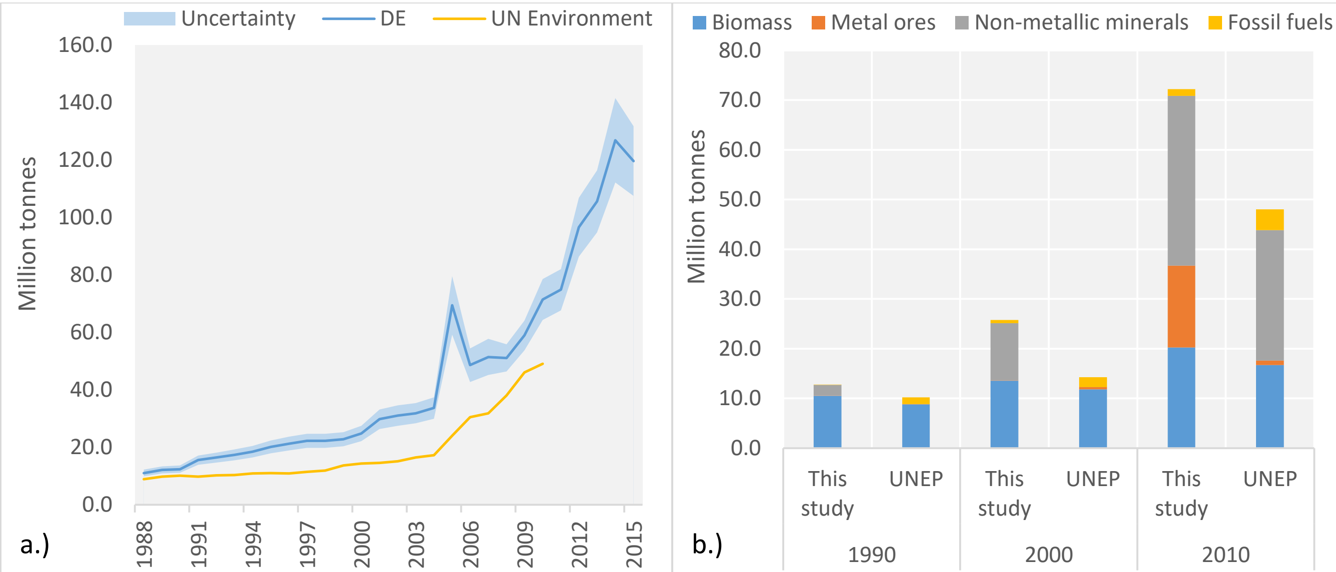

Figure 6. Comparison of results of this study and results from UN Environment (2017), a) total DE, including uncertainty for this study, b) DE by main categories

Material use and human development and comparison with other ASEAN economies

To improve the understanding of the relationship between human development and resource consumption, UNEP (2016) used the national level human development index (HDI) as the metric to cluster levels of resource extraction, consumption and trade by four major groups of countries: Low HDI, Medium HDI, High HDI, and Very High HDI. The development of HDI in Laos grew slowly, about 1.5 times compared to HDI in 1990 (see Figure 5a). In 2015 Laos was considered a medium HDI country by the index provided by UNDP (2016).

Figure 7 shows the comparison of metabolic rate and materials intensity of a group of medium HDI countries in Southeast Asia which are all members of the Association of Southeast Asian Nations (ASEAN). Data for Lao PDR from this study is compared to data for ASEAN countries from the UNEP (2016) dataset and report. Lao PDR shows the highest per-capita DMC of all six ASEAN members and has by far the worst material efficiency, almost double that of other ASEAN middle HDI countries. Even when comparing MI and metabolic rate of Lao PDR using UNEP's data, the values for Lao PDR are still higher but closer to other countries, indicating that the various data sources used in the MFA accounting influenced the comparison. The Lao economy uses domestic natural resources in a less efficient way than its neighbors, is less successful in building local value-adding industries, and accepts the highest environmental pressure on its domestic territory of the six ASEAN economies we are comparing. It is questionable whether this pathway of material extraction for infrastructure supporting primary resource exports, which has not translated into human wellbeing sufficiently well, is a good economic strategy for Lao PDR's long-term economic prospects.

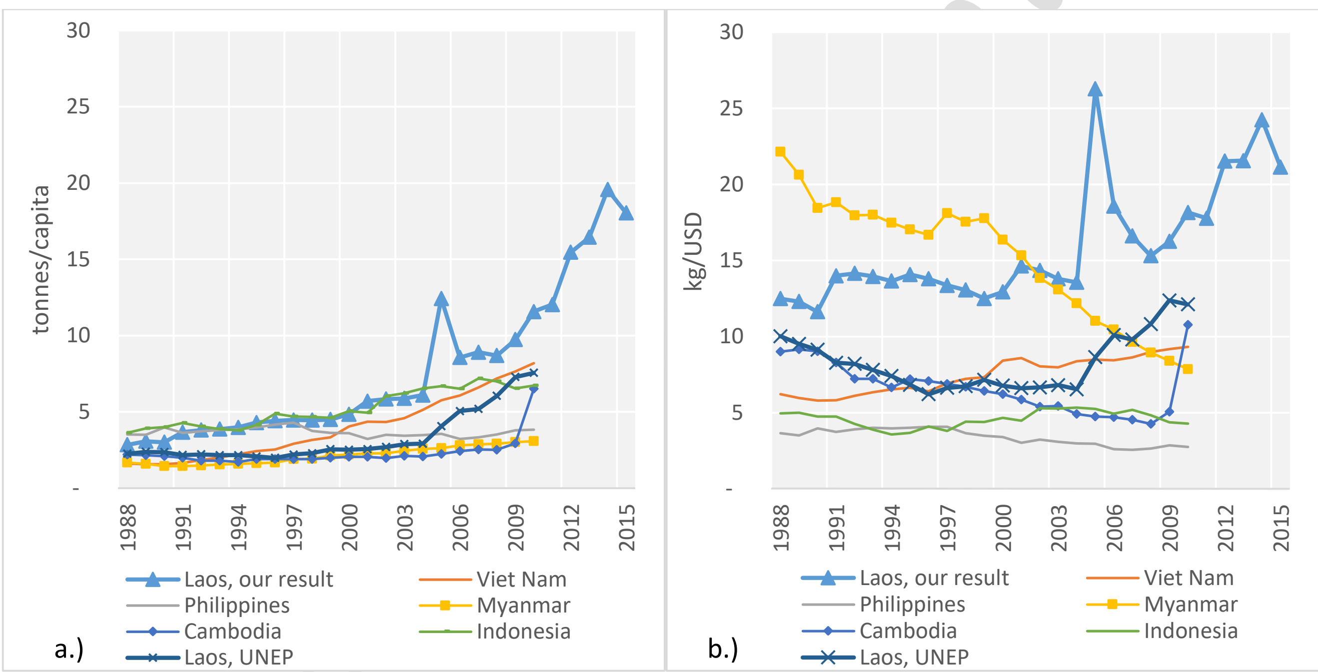

Figure 7. a. Metabolic rate (DMC per capita), b. Material intensity (DMC per GDP) in Medium HDI countries of ASEAN

Discussion

Comparison of our results with UN Environment International Resource Panel database

Lao PDR represents a special case in regard to material use in a developing country. It already has a very high level of DMC at 20 tonnes per capita, enabled by large natural resource deposits, low population density and massive foreign investment into mining and energy generation capacity leading to fast deteriorating material efficiency of the economy. Much of this development is driven by demand for materials and electricity by Lao neighbors Thailand, Viet Nam and China (Lamphayphan et al., 2015).

This economic pattern, and its environmental and social consequences, require further analysis of the environmental impacts related to pressures. It would also be wise to assess the economic and social benefits to Lao households and businesses of this resource and energy-led regional economic development strategy.

The UN Environment International Resource Panel found that by 2010, 15 tonnes of material per capita were sufficient for high human development (as measured by the HDI) and would allow for a reasonable standard of living, good educational outcomes and a long life expectancy (UNEP, 2016). Lao PDR has surpassed this level but is far from delivering the socioeconomic benefits of its high per-capita resource use.

The focus on primary resource export-oriented industries has also made the Lao economy more susceptible to fluctuations in world market prices for primary materials and has increased the vulnerability of the Lao economy to such fluctuations.

It appears obvious that policy making in Lao PDR will profit from a reliable evidence base of its resource use and that building national capability in resource accounting would be a worthwhile political objective.

Limitations of this study

Despite the large effort that has gone into the assessment of material flows in Lao PDR, this study still has some important limitations, which warrant further research. The crop residues were estimated based on default coefficients provided by Eurostat, which may not reflect actual figures for crop residues used in Lao PDR. A new intensity for concrete of Lao PDR was calculated, for the first time, but its robustness is uncertain due to assumptions made about sharing of concrete types used in the calculation. Due to the unavailability of intensity data for road construction in Lao PDR, an assumption of average intensity was made based on values provided by Eurostat, which may result in over- or under-estimation due to different road conditions. Note that sand and gravel, and aggregates used for road construction, accounted for about 37% of total DE; improving estimation approaches to estimate these materials more accurately could significantly improve the EW-MFA results. Finally, the estimation of the physical weight of trades using the "average tonne price" could possibly result in over- or under-estimation, but at least in this study we were able to compare against some available physical data and the actual amount of trade is not significant compared to total DMI. In the near future, when the Lao economy integrates into the world economy through trade, estimating physical weight from an "average tonne price" will not be necessary.

Policy implications for Lao PDR

This study has important policy implications. It shows the importance of resource governance and well-tailored policies to increase the benefits and mitigate the costs of the Lao development path.

Because of the fast increase in mining and resource- and energy-led economic development, Lao PDR faces a multitude of environmental impacts including large-scale land use change, toxic pollution and land degradation. Mining regulation and governance are weak which makes it harder to mitigate the negative impacts of the mining industry. The Lao government may consider strengthening regulation and governance for the fast-growing mining sector.

There are similar issues with regard to energy generation. Lao PDR has abundant potential for hydropower generation but most of the electricity generated is supplied to neighboring countries, leaving only about 25% for domestic consumption. In 2014, total installed capacity of hydropower plants was 3,335 MW with approximately 88% belonging to independent power producer private companies (Ministry of Energy and Mines of Lao PDR, 2015a). Undoubtedly, electricity generation has been an important contributor to socioeconomic development in Lao PDR as a whole, but it comes at the cost of decreased forest cover area (70% in 1940 to 40% in 2010; World Bank (2017b)), loss of biodiversity, and socioeconomic impacts such resettlement from the reservoir area, and other environmental impacts during the construction period. It is still questionable whether energy generation will contribute to sustainable economic development. This has been a challenge for policy makers in Lao PDR, to design innovative policy that helps minimize environmental problems and maximize benefits from this natural resource-based income to society in order to achieve the NSEDP and graduate from being a least-developed country by 2020.

One important issue for the Lao economy is to create options for value-adding and domestic manufacturing based on the large availability of primary materials from mining and agriculture. There are ample opportunities for secondary industries which would allow for higher incomes and a greater contribution to the Lao economy than current extractive and primary export-oriented sectors allow for. Value adding could occur in several sectors of the Lao PDR economy and would profit from the availability of metal resources in combination with affordable electricity, timber and non-timber forest products. Investments to build secondary industries to the mining, forestry and agriculture sectors would provide new employment, better incomes for workers and greater benefits to the Lao national accounts compared to the current sole focus on primary resource and electricity exports.

Especially the rich biological diversity of Laos and the usability of those rich biological resources for medical and cosmetic industries could be additional sources of value adding. There is additional potential in tourism and eco-tourism which need be exploited to build a diversified economy which is less susceptible to fluctuation in global demand for and world market prices of primary materials and energy. Such more diversified strategy to economic development would rely on training and capacity building of workers, upskilling of industrial leadership and would also increasingly offer opportunities for resource efficiency and recycling through improvements in eco-efficiency of the emerging secondary industries.

The Lao PDR does not have strong competitive advantage with regard to building sophisticated industrial and manufacturing operations at this time but could set itself up for the growth of its secondary industries leveraging the rich resource endowment as a first step to a more diversified economic future.

Building a more diversified industry will help avoid economic vulnerability. Recent modeling (Hatfield-Dodds et al., 2017) shows that in a global economy guided by ambitious policies for resource efficiency and greenhouse gas abatement, countries which rely on primary resource exporting as a main component of their economic development and are currently low-income economies would lose economic growth and employment. Because such global policy settings are now more likely with the Paris Agreement on Climate Change in place and the Sustainable Development Goals accepted, economic diversification is fundamental to Lao PDR's future economic prosperity.

Industrialization, urbanization and mining have also contributed to new industrial and household waste flows which overwhelm current waste management and recycling policies and capacities. Air pollution is another important new feature of the growing Lao economy. Managing waste and emissions will require well-designed policies and programs, and new infrastructure for waste collection and recycling to manage the ever-growing amounts of waste and fast-changing levels of toxicity and pollution (UNEP, 2017). The nascent manufacturing industry will profit from investment in clean production and the Lao government needs be commended for its interest and investment in green economic development (Ministry of Planning and Investment of Lao PDR, 2016). While other emerging economies in Southeast Asia have used their manufacturing growth to invest in resource efficiency and waste minimization, such policy strategies are still rare in Lao PDR (Aoki-Suzuki, 2015).

One important feature of the material flow data presented in this study is to improve the capacity of Lao to report progress on the implementation and success of the Sustainable Development Goals (SDGs) in the country. Material flow indicators can be used to report against targets 8.4, 12.2 and 12.5 of the

SDGs. How is the Lao economy tracking with regard to these targets for natural resource use and resource productivity that are understood to underpin success in human development?

Lao PDR, on its current trajectory, fails on target 8.4 which requires countries to continuously improve resource productivity of production and consumption. For the assessment of resource productivity of production, the Inter-Agency Expert Group (IAEG) for the SDGs has proposed using GDP per unit of DMC as the leading indicator. The trend in Lao PDR of decreasing resource productivity does not meet the aspiration of SDG 8.4.

Target 12.2 requires sustainable management of natural resources and will be monitored, based on the recommendation of the IAEG, using DMC per capita. Sustainable management of resources would require DMC per capita to be below the empirical observed threshold level which has clearly been surpassed by the Lao economy.

Target 12.5 asks for waste reduction and an increase in the recycling rate. To the extent that fast-rising DMC must also be interpreted as a proxy for increasing waste flows Lao also fails on this target. Since an assessment of the output side of Lao material flows has not been undertaken for this study, it is hard to judge whether the recycling rate of the Lao economy has been improving, although an overall reading of environmental pressures from the input accounts would suggest otherwise.

Conclusion

This study has developed a new dataset for material extraction and trade of materials for Lao PDR covering almost three decades (1988–2015) and mostly based on national statistical data and domestic expertise. The results of our account differ substantially from previous studies, especially for metal ores and biomass, due to more reliable information on different aspects of the accounts. The results demonstrate the need for policy innovation in Lao PDR to avoid the trap of “Dutch disease” and the related social, economic and environmental impacts. Our research suggests that well-designed policies will make a positive contribution to human development and environmental integrity in Lao PDR and will support the country to achieve the SDGs while conserving Lao PDR's natural resources and ecosystems. Innovative policies that integrate environmental, social and economic objectives will, however, require more comprehensive information about the use of materials in the economy and the related environmental impacts that go hand in hand with natural resource utilization. This study has produced a set of pressure indicators for domestic extraction and trade of materials by focusing on the input side of a material flow account. Including outflows in the analysis would allow a better understanding of environmental impacts and should be undertaken in follow-up research.

Acknowledgements

This research was partially supported by the Environment Research and Technology Development Fund (1-1402) of the Ministry of the Environment, Japan. The first author is grateful for the PhD scholarship provided by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. The authors wish to thank Karin Hosking of CSIRO for editing the final manuscript, and Jim West of CSIRO for technical help.

References

Aoki-Suzuki, C., 2015. Exploring potential policy motivation and approaches to improve resource efficiency in emerging Asia. J Mater Cycles Waste Manag, 1-15.

Ayres, R.U., Simonis, U.E., 1994. Industrial Metabolism. Restructuring for Sustainable Development. United Nations University Press, Tokyo, New York, Paris.

Bringezu, S., Potocnik, J., Schandl, H., Lu, Y.L., Ramaswami, A., Swilling, M., Suh, S., 2016. Multi-Scale Governance of Sustainable Natural Resource Use-Challenges and Opportunities for Monitoring and Institutional Development at the National and Global Level. Sustainability 8(8), 25.

Ehrlich, P.R., Holdren, J.P., 1971. Impact of population growth. Science 171, 1212-1217.

European Commission, 2017. Resource Efficiency Scoreboard. http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/index_en.htm. (Accessed 10 July 2017).

Eurostat, 2013. Economy-wide Material Flow Accounts: Compilation Guide 2013. Eurostat, Luxembourg.

FAO, 2017. FAO statistical databases. http://www.fao.org/faostat/en/. (Accessed 09 May 2017).

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schuetz, H., Schandl, H., Weisz, H., 2011. Methodology and Indicators of Economy-wide Material Flow Accounting. Journal of Industrial Ecology 15(6), 855-876.

Gerrard, P., 2004. Integrating Wetland Ecosystem Values into Urban Planning: The Case of That Luang Marsh, Vientiane,Lao PDR. IUCN − The World Conservation UnionAsia Regional Environmental Economics Programmeand WWF Lao Country Office, Vientiane, Lao PDR.

Hatfield-Dodds, S., Schandl, H., Newth, D., Obersteiner, M., Cai, Y., Baynes, T., West, J., Havlik, P., 2017. Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies. Journal of Cleaner Production 144, 403-414.

Herendeen, R.A., 1998. Ecological numeracy: quantitative analysis of environmental issues. John Wiley and Sons, New York.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecological Economics 68(10), 2696-2705.

Lamphayphan, T., Toyoda, T., Czerkawski, C., Kyophilavong, P., 2015. Export Supply of Electricity from Laos to Thailand: An Econometric Analysis. International Journal of Energy Economics and Policy 5(2).

Lao Statistics Bureau, 2015a. 40 Yeras Statistics Year Book 1975-2015. Vientiane, Lao PDR.

Lao Statistics Bureau, 2015b. Lao Population and Housing Census 2015: Provisional Report. Lao Statistics Bureau, Vientiane, Lao PDR.

Martinico-Perez, M.F.G., Fishman, T., Okuoka, K., Tanikawa, H., 2016. Material Flow Accounts and Driving Factors of Economic Growth in the Philippines. Journal of Industrial Ecology, n/a-n/a.

Miatto, A., Schandl, H., Fishman, T., Tanikawa, H., 2016. Global Patterns and Trends for Non-Metallic Minerals used for Construction. Journal of Industrial Ecology, n/a-n/a.

Ministry of Agriculture and Forestry of Lao PDR, 2015a. Agriculture statistics 1976-2015, in: Department of Planning and Cooperation (Ed.). Vientiane, Lao PDR.

Ministry of Agriculture and Forestry of Lao PDR, 2015b. Guide for Livestocks Feeding Improvement in: Department of Livestock and Fisheries (Ed.). Vientiane, Lao PDR.

Ministry of Agriculture and Forestry of Lao PDR, 2015c. Technical Standard for National Livestocks Balancing in: Department of Livestock and Fisheries (Ed.). Vientiane, Lao PDR.

Ministry of Energy and Mines of Lao PDR, 2015a. Electricity Statistics Yearbook 2014 of Lao PDR, in: Department of Energy Policy and Planning (Ed.). Vientiane, Lao PDR.

Ministry of Energy and Mines of Lao PDR, 2015b. Minerals Productions in Lao PDR 1985-2015, in: Department of Mines (Ed.). Vientiane, Lao PDR.

Ministry of Industry and Commerce of Lao PDR, 2015a. Imports and Exports of Lao PDR 2010-2015, in: Department of Planning and Cooperation (Ed.). Vientiane, Lao PDR.

Ministry of Industry and Commerce of Lao PDR, 2015b. Industrial Processing Statistics 1985-2015, in: Department of Planning and Cooperation (Ed.). Vientiane, Lao PDR.

Ministry of Planning and Investment of Lao PDR, 2016. 8th Five-Years National Socio-Economic Development Plan (2016-2020). Vientiane, Lao PDR.

Ministry of Public Works and Transportation of Lao PDR, 2015. Public Work and Transportation Statistics Year Book, in: Department of Planning and Cooperation (Ed.). Vientiane, Lao PDR.

Ministry of the Environment Government of Japan, 2016. Communiqué G7 Toyama Environment Ministers' Meeting. Ministry of the Environment Government of Japan, Toyama, Japan.

Patrício, J., Kalmykova, Y., Rosado, L., Lisovskaja, V., 2015. Uncertainty in Material Flow Analysis Indicators at Different Spatial Levels. Journal of Industrial Ecology 19(5), 837-852.

Schandl, H., Rankine, H., Fotiou, S., Stabrawa, A., 2010. Sustainable Resource Use in the Asia-Pacific Region. Journal of Industrial Ecology 14(4), 533-536.

Schandl, H., West, J., 2010. Resource use and resource efficiency in the Asia–Pacific region. Global Environmental Change 20(4), 636-647.

SIMETRIC, 2017. Mass, Weight, Density or Specific Gravity of Bulk Materials: Density of Materials https://www.simetric.co.uk/si_materials.htm. (Accessed 10 Apr. 2017).

Singh, S.J., Krausmann, F., Gingrich, S., Haberl, H., Erb, K.-H., Lanz, P., Martinez-Alier, J., Temper, L., 2012. India's biophysical economy, 1961–2008. Sustainability in a national and global context. Ecological Economics 76, 60-69.

SNL, 2016. S&P Global Market Intelligence Databse. https://www.snl.com. (Accessed 12 April 2017).

Takiguchi, H., Takemoto, K., 2008. Japanese 3R Policies Based on Material Flow Analysis. Journal of Industrial Ecology 12(5-6), 792-798.

UN COMTRADE, 2017. United Nations Commodity Trade Statistics Database. https://comtrade.un.org/data/. (Accessed 12 April 2017).

UN Environment, 2017. UN Environment Live Database. http://www.uneplive.org/country/data/LA

(Accessed 01 April 2017).

UNDP, 2016. Human Development Indicators Database: Lao People's Democratic Republic.

UNEP, 2011. Resource Efficiency: Economics and outlook for ASIA and the Pacific. CSIRO Publishing, Melbourne.

UNEP, 2013. Capacity Building and Policy Needs Assessment for Sustainable Consumption and Production. United Nations Environment Programme, Bangkok.

UNEP, 2015. Indicators for Resource Efficient and Green Asia and the Pacific. United Nations Environment Programme, Bangkok.

UNEP, 2016. Global Material Flows and Resource Productivity. An Assessment Study of the UNEP International Resource Panel. United Nations Environment Programme, Paris.

UNEP, 2017. Resource Efciency: Potental and Economic Implicatons, A report of the Internatonal Resource Panel. United Nations Environment Programme, Narobi, Kenya.

UNSD, 2017. UNSD Statistical Databases. https://unstats.un.org/unsd/databases.htm. (Accessed 01 April 2017).

Wang, H., Hashimoto, S., Moriguchi, Y., Yue, Q., Lu, Z., 2012. Resource Use in Growing China. Journal of Industrial Ecology 16(4), 481-492.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proceedings of the National Academy of Sciences of the United States of America 112(20), 6271-6276.

World Bank, 2017a. GDP per capita (current US$). http://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=LA. (Accessed 27 April 2017).

World Bank, 2017b. Lao PDR Systematic Country Diagnostic. Vientiane, Lao PDR.