Development of Renewable Energy in ASEAN Countries: Socio-economic and Environmental Impacts

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Abstract

In the last two decades, there has been a significant increase in electricity consumption per capita amongst ASEAN countries. This consumption of electricity will most likely keep increasing in the future; indicating the importance of the solid provision of electricity supply in the region. ASEAN countries, however, have concerns that keep utilising fossil-fueled electricity would deteriorate the environmental condition. Therefore, ASEAN countries seriously considering to increase their investment in renewable electricity power generations. Nonetheless, there have been only a few studies focus on the impacts of this shifting towards renewable energy toward societies' socio-economic and environmental condition. Utilise an inter-regional Social Accounting Matrix (IRSAM) across countries in the Southeast Asia region, this paper aims to compare the impacts of increasing electricity generated from fossil fuel and that from renewable resources, namely wind, hydro and solar. This paper finds that switching to renewable energy, not only can induce higher GDP compared to keep using fossil fuel, but also producing much less carbon emission. However, the poverty incidence reduction under renewable electricity development simulations is less than fossil fuel development simulation. This paper argues that the initial level of income per capita, income distribution pattern, and flow of income in an economy matter in determining the poverty reduction.

Keywords: renewable electricity, carbon emissions, inter-regional Social Accounting Matrix, ASEAN.

JEL Classification: E16, E17, I32

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1. Introduction

The Association of Southeast Asia Nations (ASEAN) was declared in 1967, aimed to foster regional cooperation in South-East Asia as well as strengthened economic and social stability in the region (ASEAN 2020). By now, ASEAN comprises of ten countries, namely Brunei Darussalam, Indonesia, Cambodia, Lao PDR, Myanmar, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. Together, in 2017, these ten countries represented around 8.55 per cent of the world's population, 3.44 per cent of world Gross Domestic Product (GDP), and 7.42 per cent of global exports.

As a result of rapid economic growth in the ASEAN region, there has been a significant increase in electricity generation and electricity consumption per capita amongst ASEAN countries as presented in Table 1. In the period 2000 to 2017, for example, almost all ASEAN countries doubled their electricity generation. Even Vietnam increased electricity generation by almost eight-time. In terms of electricity consumption, in a similar period, all ASEAN economies had significant increasing by at least more than twofold. Vietnam's electricity consumption per capita, for example, increased by more than sixfold compared to 2000. Nonetheless, on average, electricity consumption per capita for most of ASEAN countries was still below the world average as presented in Table 1. Only high and high-middle income countries in ASEAN such as Brunei, Singapore, and Malaysia achieved a relatively higher electricity consumption per capita compared to the world average.

Table 1. Total Electricity Generation and Electricity Consumption

	Total Electricity Generation (GWh)			**Electricity Consumption (MWh per capita)**		
	2000	**2010**	**2017**	**2000**	**2010**	**2017**
Brunei	2,543	3,792	4,157	7.55	8.81	8.60
Indonesia	93,325	169,755	254,868	0.39	0.64	0.90
Cambodia	448	1,000	6,998	0.03	0.14	0.50
Myanmar	5,758	7,543	22,413	0.08	0.12	0.30
Malaysia	70,458	124,787	164,503	2.75	4.15	4.80
Philippines	45,521	67,892	94,847	0.50	0.64	0.80
Singapore	31,759	46,547	52,364	7.58	8.68	9.20
Thailand	96,096	159,867	186,505	1.45	2.31	2.90
Vietnam	26,741	94,940	198,659	0.29	1.02	1.90
World	15,518,865	21,616,255	25,720,185	2.39	2.96	3.20

Notes: Data for Lao PDR are not available. Source: IEA (2020).

Electricity consumption in ASEAN economies will most likely keep increasing in the future. Hence, the provision of electricity supply is an important issue for ASEAN member countries. Electricity can be generated by mixing energy resources from either fossil fuels or renewable energy. Nonetheless, fossil fuel electricity generations deteriorate environmental condition due to, among others, their carbon emissions (Goh, Ang and Xu 2018). Fortunately, the ASEAN region has a great potential to develop renewable energy since there is a significant investment in renewable energy as well as untapped renewable energy potential (IRENA, 2018). Therefore, ASEAN member countries aim to develop its renewable energy by increasing the share of renewable energy in the energy mix up to 23 per cent by 2025 (ACE 2015).

There are ample studies on the impacts of renewable energy. For instances, a study by Gibon et al. (2017) focuses on renewable energy technology and its impacts on human health globally. Another study examines the marginal external benefits of wind turbines and solar panels on carbon emissions in Texas (Novan 2015). Similarly, Corona et al. (2016) estimate socio-economic and environmental life cycle impacts of Concentrated Solar Power (CSP) by using multiregional input-output analysis in Spain. Nonetheless, most of the studies evaluate the impacts of renewable energy development from a single renewable energy technology development or within a country perspective. There are fewer comprehensive studies on how increasing renewable energy could affect the economy, income distribution, and carbon emissions across countries in a specific region such as ASEAN. Therefore, the objective of this paper is to observe the socio-economic and environmental impacts of the rise of renewable energy share in ASEAN countries. The main estimations are based on Inter-Regional Social Accounting Matrices (IRSAM) as a simple general equilibrium model. In this paper, the socio-economic and environmental impacts are analysed according to three main categories: macroeconomic indicators such as GDP and sectoral changes; carbon emissions for the environmental angle; and socio-microeconomic indicators such as poverty incidence and income per percentile households in rural and urban households. By using three different perspectives, this paper provides a comprehensive observation of the impacts of renewable energy development in the ASEAN region.

To achieve this goal, this paper develops an East Asia IRSAM consisting Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, and the Rest of ASEAN (Brunei, Lao PDR, Myanmar, and Cambodia) as well as Australia, China, Japan, South Korea, and India. Further, this paper utilises this IRSAM to stimulate the socio-economic and environmental impact of the development of wind power, hydropower, and solar power electricity generators in ASEAN.

There are several contributions of this paper to the existing literature. Firstly, this paper extends the traditional Constrained Fixed Price Multiplier (CFPM) analysis developed by Lewis and Thorbecke (1992), by Resosudarmo and Thorbecke (1998), and by Hartono and Resosudarmo (2008) to an Inter-Regional Constrained Fixed Price Multiplier (IRCFPM) analysis. Secondly, this paper develops a household income microsimulation model to be able to observe the impact of a policy on household income distribution using an IRSAM (Nurdianto and Resosudarmo 2016). Also, IRSAM in this paper is connected to a satellite carbon emission model to be able to observe the impact of the economic changes on carbon emission (Resosudarmo and Thorbecke, 1998).

Based on these three analyses, this paper sheds light on the socio-economic and environmental impacts of an increasing share of renewable electricity across ASEAN member countries. This paper finds that increasing renewable electricity have higher impacts on macroeconomics indicators such as higher GDP and more spill over to non-energy sectors than fossil fuel development. Also, renewable electricity development reduces carbon emissions more than fossil fuel development. Nonetheless, the deployment of renewable energy in ASEAN countries could not reduce poverty incidence as much as fossil fuel electricity development.

The rest of this paper is organised as follows. Section 2 explains further the methodology and the measurement of the socio-economic impacts. Section 3 describes the data that is used in this paper in more detail. Section 4 presents the details of the simulations that are used in this paper. Section 5 presents and discuss the different impacts' magnitude in each ASEAN country from socio-economic and environmental aspects. Also, this section examines the potential determinants of the results. Finally, the last section concludes with some policy implications.

2. Methodology

The first part of this section the derivation of the inter-regional CFPM to evaluate the impacts of output changes of constrained endogenous accounts on non-constrained endogenous accounts (Resosudarmo and Thorbecke, 1996; Hartono and Resosudarmo, 2008)[2]. A simplified structure of IRSAM can be presented as in Figure 1. The figure describes three regions which are regions 1, 2 and 3. Each region consists of production activities, production factors and institutions. The exogenous accounts are government, savings, and taxes that are included in the EXC column and row accordingly[3].

	Region 1	**Region 2**	**Region 3**	**EXC**	**TOTAL**
Region 1	A_{NC}^{11}	$Q^{12}\ A_{NC}^{12}$	A_{NC}^{13}	X_{NC}^{1}	Y_{NC}^{1}
Region 2	R^{21} A_{NC}^{21}	$A_{C}^{22}\quad R^{22}$ $Q^{22}\quad A_{NC}^{22}$	R^{23} A_{NC}^{23}	X_{C}^{2} X_{NC}^{2}	Y_{C}^{2} Y_{NC}^{2}
Region 3	A_{NC}^{31}	$Q^{32}\quad A_{NC}^{32}$	A_{NC}^{33}	X_{NC}^{3}	Y_{NC}^{3}
EXC	l^{1}	l^{2}	l^{3}	t	Y_{E}
TOTAL	$(Y_{NC}^{1})'$	$(Y_{C}^{2})'\quad (Y_{NC}^{2})'$	$(Y_{NC}^{3})'$	$(Y_{E})'$	

Figure 1. Structure of three regions IRSAM with constrained sectors.

Total income in region 1 and region 3 are denoted by Y_{NC}^{1} and Y_{NC}^{3} respectively (Figure 1). None of them is constrained. Let assume that in region 2, there are constrained and unconstrained sectors. The constrained sectors in this paper are renewable and non-renewable electricity sectors, while other sectors are defined as unconstrained sectors. The total income vectors of the constrained sector in region 2 are then defined as Y_{C}^{2} and total income vectors of the non-constrained sector in region 2 is Y_{NC}^{2}. Term A_{C}^{22} is a matrix of average expenditure propensities of the constrained sector in region 2. Similarly, terms A_{NC}^{11}, A_{NC}^{22}, and A_{NC}^{33} are matrices of average expenditure propensities of non-constrained sectors in region 1, region 2, and region 3 respectively. Further, terms A_{NC}^{12}, A_{NC}^{13}, A_{NC}^{21}, A_{NC}^{23}, A_{NC}^{31}, and A_{NC}^{32} are matrices of non-constrained average expenditure propensities for region 1, region 2, and region 3. Terms l^{1}, l^{2}, and l^{3} are leakages while X_{NC}^{1}, X_{C}^{2}, X_{NC}^{2}, and X_{NC}^{3} are vectors of injection. Finally, t is an exogenous vector in IRSAM.

Figure 1 can be expressed mathematically as follows.

[2] The inter-regional CFPM approach is relatively different to standard IRSAM multiplier. The explanation and derivation of standard IRSAM multiplier, for example, can be found in Resosudarmo et al. (2009).

[3] The detail of constructing East Asia IRSAM is available upon request to the author.

$$d\begin{bmatrix} Y_{NC}^1 \\ Y_C^2 \\ Y_{NC}^2 \\ Y_{NC}^3 \end{bmatrix} = \begin{bmatrix} A_{NC}^{11} & Q^{12} & A_{NC}^{12} & A_{NC}^{13} \\ R^{21} & A_C^{22} & R^{22} & R^{23} \\ A_{NC}^{21} & Q^{22} & A_{NC}^{22} & A_{NC}^{23} \\ A_{NC}^{31} & Q^{32} & A_{NC}^{32} & A_{NC}^{33} \end{bmatrix} d\begin{bmatrix} Y_{NC}^1 \\ Y_C^2 \\ Y_{NC}^2 \\ Y_{NC}^3 \end{bmatrix} + d\begin{bmatrix} X_{NC}^1 \\ X_C^2 \\ X_{NC}^2 \\ X_{NC}^3 \end{bmatrix} \quad (1)$$

The matrices in equation (1) can be elaborated into four equations and rearranged, following Resosudarmo and Thorbecke (1996) and, in such that equation (1) can be derived to become the following (see Supplement A for the derivation).

$$\begin{bmatrix} Y_{NC}^1 \\ Y_{NC}^2 \\ X_C^2 \\ Y_{NC}^3 \end{bmatrix} = \begin{bmatrix} (I - A_{NC}^{11}) & -A_{NC}^{12} & 0 & -A_{NC}^{13} \\ -R^{21} & -R^{22} & -I & -R^{23} \\ -A_{NC}^{21} & (I - A_{NC}^{22}) & 0 & -A_{NC}^{23} \\ -A_{NC}^{31} & -A_{NC}^{32} & 0 & (I - A_{NC}^{33}) \end{bmatrix}^{-1} \begin{bmatrix} I & Q^{12} & 0 & 0 \\ 0 & -(I - A_C^{22}) & 0 & 0 \\ 0 & Q^{22} & I & 0 \\ 0 & Q^{32} & 0 & I \end{bmatrix} d\begin{bmatrix} X_{NC}^1 \\ Y_C^2 \\ X_{NC}^2 \\ X_{NC}^3 \end{bmatrix} \quad (2)$$

Using equation (2), hence, we can observe the impact of a change in Y_C^2 on Y_{NC}^1, Y_{NC}^3, Y_{NC}^2 and X_C^2; i.e, in this paper, the impact of an output change of renewable or non-renewable electricity sector in region 2 to all endogenous accounts in regions 1 and 3, representing the spillover impacts, and non-constrained endogenous account in region 2.

The next part of this section is on how to develop a household income microsimulation model based on an IRSAM. Household income microsimulation models usually have been developed to be part of the top-down computable general equilibrium (CGE) model approach (Bourguignon and Bussolo, 2013; Yusuf and Resosudarmo, 2015; Nurdianto and Resosudarmo, 2016). This paper, hence, offers another approach to implement a household income microsimulation model to be integrated with an IRSAM analysis.

There are two steps in conducting the microsimulation. The first step is to compute income for the households in urban and rural areas as presented in equation (3).

$$H_c^{ur} = \sigma_c^{ur} sl^{ur} \sum_v \sum_q \frac{N_c^{v,q}}{\sum_c N_c^{v,q}} lb^{v,q} + \varsigma_c^{ur}\, inc\_sh_c^{ur} sh^{ur} \sum_w \sum_q nlb^{w,q} \quad (3)$$

where
ur = index for urban or rural household;
c = index for 100 groups of household based on population percentile
v = index for labour income type: skilled and unskilled labour;
w = index for non-labour income type: land, natural resources, and capital;
q = index for sector in IRSAM;
σ_c^{ur} = scaling factors of total labour income to IRSAM value;
sl^{ur} = shares of labour factor incomes to the total income of an urban or rural household;
$N_c^{v,q}$ = number of labour type v by sector q in household c[4];
$lb^{v,q}$ = total type v labour income in sector q;
ς_c^{ur} = scaling factors of total non-labour income to IRSAM value;
sh^{ur}= shares of non-labour factor incomes to the total income of an urban or rural household;
$inc\_sh_c^{ur}$ = percentage of income based on population percentile;

[4] This paper uses different household surveys for each ASEAN member countries to extract the number of labour for each sector. Further details of the surveys are presented in the next section on data.

$nlb^{w,q}$ = total type w non-labour income in sector q.

Equation (3) defines the total income that can be obtained by percentile c household in urban and rural areas. Equation (3) assumes that a household receives income from either skilled and unskilled labour income (i.e. the first part of equation (3): $\sigma_c^{ur} sl^{ur} \sum_v \sum_q \frac{N_c^{v,q}}{\sum_c N_c^{v,q}} lb^{v,q}$), and non-labour income, such as land, capital, and natural resources (i.e. the second part of equation (3): $\varsigma_c^{ur}\ inc\_sh_c^{ur} sh^{ur} \sum_w \sum_q nlb^{w,q}$).

On the household labour income, the first part of the equation (3) distributes the total type v labour income in sector q $(lb^{v,q})$ to each percentile of household group c based on their share of labour type v in sector q $\left(\frac{N_c^{v,q}}{\sum_c N_c^{v,q}}\right)$. This distributed labour income then re-distributed to rural and urban households based on the share of labour factor incomes to the total income of rural and urban areas (sl^{ur}). Since the total labour income is obtained from the IRSAM, while the actual household labour income per percentile obtained from the household survey in each country, some fixed adjustments are needed (σ_c^{ur}).

Similarly, on the household non-labour income, the second part of the equation (3) sums up the total type w non-labour income from sector q $(nlb^{w,q})$ to the total non-labour income in a country $(\sum_w \sum_q nlb^{w,q})$. It then distributes this total non-labour income in a country to rural and urban household groups (sh^{ur}). Finally, it redistributes this urban and rural household non-labour income to each percentile household $(inc\_sh_c^{ur})$ based on the information on income share per each percentile household obtained from a household survey data in a country. Similar to labour income, some fixed adjustments are needed (ς_c^{ur}) since the total non-labour income is obtained from the IRSAM and the actual household non-labour income per percentile obtained from the household survey in each country.

As previously mentioned, the different values of labour and non-labour types' incomes in each sector are obtained from the IRSAM. The changes of these values due to some simulations will also be obtained from the IRSAM. Two main assumptions are needed to be able to do so. Firstly, this paper uses the accounting identity in IRSAM, in which the total payment of activities for production factors should be equal to the total of income of all institutions such as households, government, and firms. Specifically, this paper computes the changes of production factor incomes for urban and rural households. The production factor incomes for the households are simply intersections between households rows with sectoral expenditure columns. Secondly, following Thorbecke and Jung (1996), this paper assumes that there exists excess capacity, in all production sectors. Therefore, any increase in demand of a sector could be fulfilled by increasing the output of the corresponding sector that allows constant price. The excess of capacity assumption also allows the assumption that the average propensity expenditure matrix is constant.

Specifically, let $\boldsymbol{S}$ is the square matrix of IRSAM with ixj dimension, where q, v, and w are subsets of i. For each country, endogenous matrix **A** for production factor income block for labour income is defined as $a^{v,q} = \frac{lb^{v,q}}{S^q}$ where $a^{v,q}$ is an element of matrix **A** at skilled and unskilled labours rows and column sector q. S^q is the total value of sector q of IRSAM. On non-labour income, the endogenous matrix **A** for production factor income block for non-labour income is defined as $a^{w,q} = \frac{nlb^{w,q}}{S^q}$ where $a^{w,q}$ is an element of matrix **A** at land, natural resources, and capital rows and column sector q. Holding $a^{v,q}$ and $a^{w,q}$ constant, if there is an exogenous shock which causes the new value of each sectoral output becomes $S^{q'}$, the new value of labour and non-labour incomes, $lb^{v,q'}$ and $nlb^{w,q'}$, can be computed as $lb^{v,q'} = a^{v,q}\, S^{q'}$ and $nlb^{w,q'} = a^{w,q}\, S^{q'}$ respectively.

At the baseline, the total values of each sector q (S^{q}) is obtained directly from IRSAM. For each simulation, there will new values of each sector q ($S^{q'}$) that corresponds to the new value of the constrained sector (Y_C^2) as the shock in equation (2).

The second step is to compute changes in poverty incidence. After distributes the income across different type of households both in urban and rural areas using equation (3), this paper computes poverty incidence for each simulation by using a method developed in Yusuf and Resosudarmo (2015).

The final part of this section is on the carbon emission model. This paper simply computes sectoral emissions per unit output in each sector, which is sectoral emissions divided by sectoral output. Next, sectoral emissions per unit output are multiplied by sectoral output changes that are extracted from the inter-regional Constrained Fixed Price Multiplier results. Finally, changes in carbon emissions can be computed by comparing the summation of sectoral emissions to the baseline emissions values by each country.

3. Data

The main data for this paper is the East Asia IRSAM which is constructed mainly from the GTAP 9 database and GTAP Power (Peters 2016). GTAP 9 database is a global database that describes bilateral trade patterns, production, and consumption, as well as intermediate use of commodities and services. GTAP Power itself has highly disaggregated the electricity sector into transmission and distribution, baseload generating technologies, and peak generating technologies (Peters 2016). This paper uses 2011 as its reference year in million USD since it provides the latest available dataset. Also, the East Asia IRSAM covers seven ASEAN member countries (Indonesia, Malaysia, Singapore, Thailand, Vietnam, the Philippines, and rest of ASEAN) as well as Australia, China, India, Japan, and South Korea.

This paper extracts and converts the GTAP Power 9 Database into GDX file format to be compatible with General Algebraic Modelling System (GAMS) software, following McDonald and Thierfelder (2004). Next, after the database is translated into GAMS format, this paper constructs a specific GAMS code to construct IRSAM based on Nurdianto (2011). Further, the structure of IRSAM closely follows Round (1985) and Resosudarmo et al. (2009) where the endogenous accounts are production activities, household accounts, and value-added. The exogenous accounts are firms, government, taxes, and savings-investment.

There are several distinct features of the East Asia IRSAM. Firstly, East Asia IRSAM disaggregates the electricity sector into four distinct sectors, namely wind, hydro, solar, and others (nuclear, coal, oil, gas). Secondly, the East Asia IRSAM disaggregates regional household account into rural and urban households as well as firm and government accounts. Disaggregation of the regional household account that follows Nurdianto (2011) and Delpiazzo and Standardi (2014) allows for richer specification in the model, in particular, a direct connection between private household and government accounts, and capital account as well as for inter-institutional transfer in each region (McDonald and Sonmez, 2004). Thirdly, it introduces inter-institutional transfer from the government to the household in the form of social expenditures by the government by taking a percentage of social expenditure to GDP for each observed country. Finally, the East Asia IRSAM has government fiscal balance as a percentage of GDP of each country, which implies that the government has a surplus or deficit in their account that does not exist in the original GTAP database. Table 2 describes the selected macro and micro indicators of ASEAN countries that are extracted from the East Asia IRSAM and constructed from various survey data.

In terms of emissions dataset, this paper extracted carbon emissions in the millions of tonnes of CO_2 from the GTAP database. The GTAP database provides carbon emissions by country and sectoral into five different fuel types, namely electricity, coal, oil, gas, petroleum and coal products, and gas manufacture sectors.

Regarding microsimulation, this paper utilises several survey data across ASEAN countries. For Indonesia, this paper uses the 2011 National Socio-Economic Survey (SUSENAS). The 2014 Household Living Standards Survey (VHLSS) is used for Vietnam. For the Philippines, this paper uses a combination of the 2012 Family Income and Expenditure Survey (FIES) as well as the 2012 Labour Force Survey (LFS). Finally, for Thailand, this paper extracts the dataset from the 2011 National Socio-Economic Survey (SES). Due to the limitation of the data, this paper assumes that the sectoral labour share, as well as the income share of Malaysia, is similar to that of Thailand, while Rest of ASEAN income share is assumed similar to Vietnam. This paper does not conduct any analysis of poverty incidence in Singapore since early computation indicates that there is no poverty incidence based on the World Bank poverty line.

4. Simulation Scenarios

There are four simulations implemented in this paper:

- The first simulation (SIM1) is the baseline condition scenario representing a business as usual situation. This scenario assumes that each ASEAN member country will grow their electricity demand by 10 per cent and all of these demands will be supplied by fossil fuel-generated electricity powerplants, in particular electricity generated from a coal-fired power plant.
- The second simulation (SIM2) is the windpower scenario. This scenario assumes that the 10 per cent increase in electricity demand will be supplied by wind power electricity powerplants.
- The third simulation (SIM3) is the hydropower scenario. In this simulation, increasing in the electricity demand is fulfilled by increasing output from hydropower electricity power plants.
- In the last simulation (SIM4) is the solar power scenarios. This scenario focuses on solar-generated electricity development in ASEAN; i.e. the 10 per cent increase in electricity demand will be supplied by solar powerplants.

In these three last simulations, this paper observes the impacts of introducing renewable energy to shift away from conventional electricity generation; i.e. using fossil fuel, into renewable resources. To make it comparable across simulations, this paper assumes that increasing renewable electricity output within an ASEAN country is similar to the increasing value of fossil-fuelled electricity's output.

Table 2. Selected Indicators of ASEAN in Renewable East Asia IRSAM

	IDN	MYS	PHL	SGP	THA	VNM	XSE
Gross Domestic Product (in million USD)	807,817	276,128	214,283	253,874	310,442	111,994	87,306
CO2 Emissions (in million tonnes)	259	95	35	24	149	77	14
Energy Sectors (in million USD)							
Electricity	16,631	10,190	7,435	8,002	12,834	16,933	1,896
- Wind	0	0	9	0	0	19	0
- Hydro	98	77	976	0	86	5,350	584
- Solar	0	0	0	3	3	0	0
- Others	16,534	10,113	6,450	7,999	12,745	11,564	1,312
Coal	33,580	160	401	0	717	3,995	25
Oil	33,680	17,625	591	117	7,314	11,054	5,875
Gas	15,927	8,580	4	0	2,970	96	6,152
PCP	54,084	35,568	14,440	73,102	70,207	8,399	1,732
GMD	7,377	5,393	857	12	8,298	2,190	905
Production Factor (in million USD)							
Unskilled Labour	262,496	62,916	39,962	25,684	69,465	34,774	22,597
Skilled Labour	79,387	56,173	42,103	87,989	46,382	16,256	8,706
Non-Labour	465,919	157,040	132,219	140,201	194,592	60,964	56,003
Poverty Incidence (using the World Bank poverty line)							
Urban	9.77	2.33	11.73		5.46	8.39	7.73
Rural	12.91	4.23	41.15		15.97	64.78	55.55
Urban and Rural	13.03	2.40	25.99		9.38	35.05	20.78

Notes: IDN= Indonesia; MYS= Malaysia; PHL= the Philippines; SGP=Singapore; THA=Thailand; VNM= Vietnam; XSE = Rest of ASEAN; PCP= Petroleum and Coal Products; GMD= Gas Manufacture Distribution.

5. Results

5.1 Macroeconomic impacts

Table 3 shows that the development of renewable electricity in SIM2 to SIM4 eventually induces higher GDP than SIM1. For instances, in SIM2 and SIM3, Indonesia's GDP change is around 0.18 per cent higher than SIM1's. Similarly, the Philippines, Thailand, and the Rest of ASEAN obtain higher GDP in SIM2, SIM3, and SIM4 by more than 0.05 per cent than that of SIM1, while Vietnam among others achieves the highest GDP change by more than 0.20 per cent changes relative to SIM1. In short, Table 3 reveals that the development of fossil fuel power electricity could generate higher GDP. Nonetheless, renewable electricity development could be more beneficial due to the relatively higher GDP changes.

There are several ASEAN countries without particular renewable electricity sources such as Malaysia, Singapore, and Vietnam. In these cases, the macroeconomic impacts of renewable electricity development are negative compared to SIM1. These negative impacts imply that GDP still changes positively, nonetheless the GDP levels in these simulations are below

SIM1's GDP. The main reason for these results is there are fewer spillover effects of renewable electricity sectors to the whole economy.

Table 3. ASEAN Member Countries Gross Domestic Product Changes

	SIM1 (mn USD)	SIM2 (% change)	SIM3 (% change)	SIM4 (% change)
Indonesia	809,163	0.18	0.18	0.12
Malaysia	276,704	0.00	0.21	-0.21
Philippines	215,123	0.15	0.14	0.17
Singapore	254,131	-0.10	-0.10	0.84
Thailand	311,507	0.17	0.17	0.17
Vietnam	112,934	0.28	0.26	-0.83
Rest of ASEAN	87,448	-0.16	0.07	0.07

Notes: mn USD denotes million USD; column SIM1 shows the GDPs of ASEAN countries under SIM1. Columns SIM2, SIM2, SIM3 show how much ASEAN countries' GDPs be different compared to those under SIM1. Therefore, % Changes for SIM2, SIM3, and SIM4 indicate percentage changes relative to the SIM1; SIM1 simulates 10 per cent increase of fossil fuel electricity sector's output, SIM2 simulates increase of wind power electricity sector's output at a similar value of SIM1, SIM3 simulates increase of hydropower electricity sector's output at a similar value of SIM1, SIM4 simulates increase of solar power electricity sector's output at a similar value of SIM1.

In terms of energy-related sectoral changes, Table 4 reveals that as ASEAN economies develop more renewable electricity as in SIM2 to SIM4, there is a significant decrease in the energy-related sectors' output relative to SIM1. For example, in Indonesia, the energy-related sectors'output in SIM2, SIM3, and SIM4 reduce by around 3 per cent for GMD and 1 per cent for petrol compared to SIM1. Similarly, for other ASEAN economies, the reduction of output of energy-related sectors are significant, in particular for Coal, Gas, and GMD. Also, despite the types of technology used to generate renewable electricity, the impacts of the energy sector are relatively similar across ASEAN countries. For example, there are no significant differences in energy sectors changes across SIM2, IM3, and SIM4.

In terms of non-energy related sectors, Figure 2 comparing the impacts of renewable energy development in SIM2, SIM3, and SIM4 to SIM1. The figure indicates that as a country moves towards renewable electricity sources, the spillover which is mainly contained by energy-related sector is now dispersed into other sectors. The dispersion pattern of each country might depend on the backward and forward linkages across sectors in each economy. For Indonesia and the Philippines, almost all sectors receive positive spillover compared to SIM1. These two countries exhibit a similar pattern of sectoral changes. For instances, in the primary sector, agriculture, farming, and fishing change relatively higher than in other sectors. Similar percentage changes also occur in services sectors such as water, trade, and dwellings. The manufacture sectors also receive positive spillover at less magnitude. However, the pattern in Indonesia and the Philippines can not be found in Thailand and Vietnam. For Thailand, while agriculture sectors have positive spillover due to renewable energy development, it has negative changes for wood and metal products. Also, there is a significant reduction in outputs for almost all services sectors. Further, even though Vietnam experiences negative spillover relative to SIM1 when developing more hydropower for electricity, there are positive spillover if Vietnam develops wind power electricity in SIM2.

In short, the macroeconomic impacts non-fossil fuel development are positive for the economy. Renewable electricity development, hence, could be more beneficial since it induces larger distribution impacts across primary, secondary, and tertiary sectors.

Table 4. Impacts on Energy Sectors of ASEAN countries

		Coal	**Oil**	**Gas**	**PCP**	**GMD**
Indonesia	SIM1 (mn USD)	33,851.65	33,984.15	15,978.37	54,807.63	7,624.27
	SIM2 (% Change)	-0.80	-0.82	-0.30	-1.22	-3.20
	SIM3 (% Change)	-0.80	-0.83	-0.31	-1.23	-3.21
	SIM4 (% Change)	-0.80	-0.85	-0.31	-1.25	-3.21
Malaysia	SIM1 (mn USD)	175.42	17,693.68	8,590.21	35,748.53	5,741.89
	SIM2 (% Change)	-9.51	-0.39	-0.12	-0.51	-6.46
	SIM3 (% Change)	-8.67	-0.35	-0.10	-0.45	-6.05
	SIM4 (% Change)	-8.68	-0.39	-0.12	-0.50	-6.07
The Philippines	SIM1 (mn USD)	423.80	593.27	4.40	14,508.70	939.14
	SIM2 (% Change)	-5.31	-0.26	-1.30	-0.31	-8.74
	SIM3 (% Change)	-5.31	-0.27	-1.30	-0.32	-8.74
	SIM4 (% Change)	-5.31	-0.26	-1.29	-0.31	-8.74
Singapore	SIM1 (mn USD)	0.01	117.44	0.00	73,297.12	11.92
	SIM2 (% Change)	-0.02	-0.26	-0.71	-0.27	-1.61
	SIM3 (% Change)	-0.02	-0.26	-0.71	-0.27	-1.61
	SIM4 (% Change)	-0.02	-0.25	-0.66	-0.26	-1.38
Thailand	SIM1 (mn USD)	770.73	7,327.62	3,093.38	70,335.09	8,894.60
	SIM2 (% Change)	-6.96	-0.10	-3.95	-0.09	-6.68
	SIM3 (% Change)	-6.96	-0.11	-3.96	-0.10	-6.69
	SIM4 (% Change)	-6.96	-0.11	-3.96	-0.10	-6.69
Vietnam	SIM1 (mn USD)	4,076.55	11,098.16	97.04	8,470.33	2,383.74
	SIM2 (% Change)	-1.88	-0.20	-0.53	-0.29	-8.13
	SIM3 (% Change)	-1.90	-0.23	-0.62	-0.39	-8.14
	SIM4 (% Change)	-1.99	-0.40	-1.01	-0.84	-8.15
Rest of ASEAN	SIM1 (mn USD)	26.08	5879.99	6193.80	1742.52	921.45
	SIM2 (% Change)	-2.99	-0.09	-0.67	-0.61	-1.74
	SIM3 (% Change)	-2.97	-0.07	-0.67	-0.51	-1.69
	SIM4 (% Change)	-2.97	-0.08	-0.67	-0.52	-1.69

Notes: mn USD denotes million USD; column SIM1 shows the energy sectors' output values of ASEAN countries under SIM1. Columns SIM2, SIM2, SIM3 show how much ASEAN countries' energy sectors' output values be different compared to those under SIM1. Therefore, % Changes for SIM2, SIM3, and SIM4 indicate percentage changes relative to the SIM1; SIM1 simulates 10 per cent increase of fossil fuel electricity sector's output, SIM2 simulates increase of wind power electricity sector's output at a similar value of SIM1, SIM3 simulates increase of hydropower electricity sector's output at a similar value of SIM1, SIM4 simulates increase of solar power electricity sector's output at a similar value of SIM1.

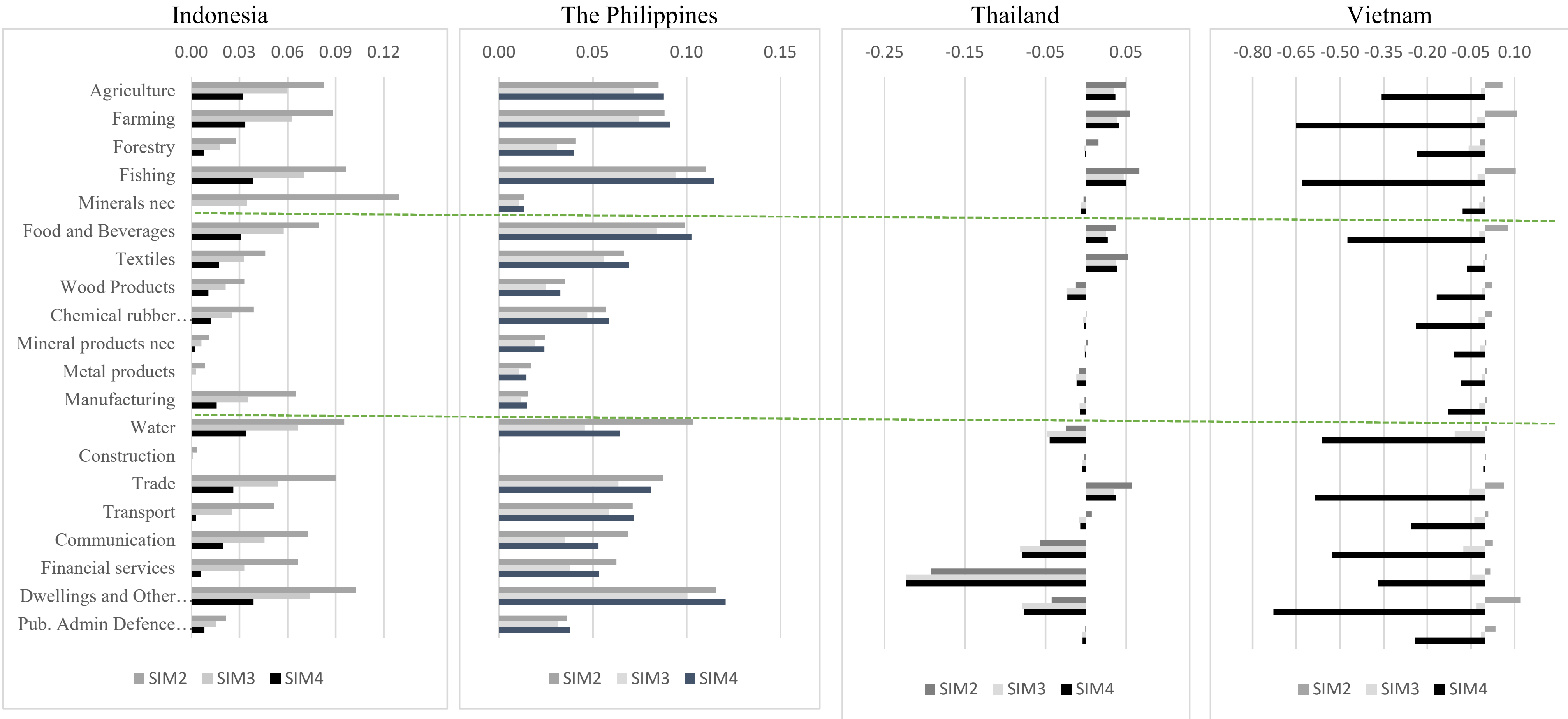


Figure 2. Impacts on Non-Energy Sectors of ASEAN countries (in %)

Notes: % changes indicate percentage changes relative to the SIM1. SIM2 simulates increase of wind power electricity sector's output at a similar value of SIM1, SIM3 simulates increase of hydropower electricity sector's output at a similar value of SIM1, SIM4 simulates increase of solar power electricity sector's output at a similar value of SIM1.

5.4 Microeconomic impacts

This section presents the microeconomic impact of increasing renewable electricity output's on poverty incidence. It is expected that higher renewable electricity outputs in the economy lead to higher incomes for the households and, as a result, there should be a reduction in the poverty incidence. Nonetheless, Table 5 reveals that compared to fossil fuel electricity development in SIM1, the development of renewable electricity seems to have relatively lower impacts on poverty incidence reductions. Such that, SIM1's poverty incidence reduction is higher than SIM2 to SIM4. This paper also finds that the poverty incidence difference between SIM1 and other simulations are relatively higher in rural households compared to urban households. For instances, in SIM2, the rural households in the Philippines experience poverty incidence reduction by 0.01 per cent, relatively higher than urban households' poverty reduction that relatively unchanged. Conversely, in Vietnam, the rural poverty incidence reduction in SIM2 is relatively higher than SIM1 at around 0.06 per cent difference.

Even though the Philippines and Vietnam exhibit a significant contrast in poverty incidence reduction compared to SIM1, there are some countries which have a relatively similar level of poverty reduction despite different simulation settings such as Indonesia and Malaysia. For Indonesia, the differences between SIM1 compared to other simulations are almost zero, an indication that there is no difference in poverty reduction across simulations. Malaysia also exhibits a similar pattern with relatively higher magnitudes at around 0.01 to 0.02 per cent.

Table 5. Changes in Percentage of Poverty Incidence

		Urban			**Rural**		
		Base	**Sim**	**Δ**	**Base**	**Sim**	**Δ**
SIM2	Indonesia	9.76	9.76	0.00	12.90	12.90	0.00
	Malaysia	2.32	2.33	0.01	4.21	4.23	0.02
	Philippines	11.69	11.69	0.00	41.05	41.04	-0.01
	Thailand	5.42	5.44	0.02	15.91	15.94	0.03
	Vietnam	8.32	8.33	0.01	64.60	64.66	0.06
	Rest of ASEAN	7.72	7.73	0.01	55.50	55.55	0.05
SIM3	Indonesia	9.76	9.77	0.01	12.90	12.90	0.00
	Malaysia	2.32	2.32	0.00	4.21	4.22	0.01
	Philippines	11.69	11.69	0.00	41.05	41.05	-0.01
	Thailand	5.42	5.44	0.02	15.91	15.94	0.04
	Vietnam	8.32	8.34	0.02	64.60	64.68	0.08
	Rest of ASEAN	7.72	7.72	0.00	55.50	55.50	0.00
SIM4	Indonesia	9.76	9.76	0.00	12.90	12.90	0.00
	Malaysia	2.32	2.33	0.01	4.21	4.23	0.02
	Philippines	11.69	11.69	0.00	41.05	41.04	-0.01
	Thailand	5.42	5.44	0.02	15.91	15.94	0.04
	Vietnam	8.32	8.39	0.07	64.60	64.78	0.18
	Rest of ASEAN	7.72	7.72	0.00	55.50	55.51	0.01

Notes: Base= SIM1 poverty incidence; Sim=Simulation value; Δ= percentage difference between SIM1 and other simulations values; SIM1 simulates 10 per cent increase of fossil fuel electricity sector's output, SIM2 simulates increase of wind power electricity sector's output at a similar value of SIM1, SIM3 simulates increase of hydropower electricity sector's output at a similar value of SIM1, SIM4 simulates increase of solar power electricity sector's output at a similar value of SIM1.

At least there are three factors determines poverty incidence reduction across simulations: the initial level of income per capita; the pattern of income distribution; and income flow in an economy. In terms of the initial level of income per capita, microsimulation results indicate that Indonesia has a relatively higher initial income per capita compared to Vietnam and the Philippines. For example, the poorest percentile in Indonesia has an annual income per capita around 69.2USD. It is relatively higher than Vietnam at approximately 32.9USD and the Philippines at around 16.48USD. Also, rural income per capita usually lower than urban income per capita. Any small increase in income per capita, hence, will have more effects on Vietnam and the Philippines, in particular in the rural areas.

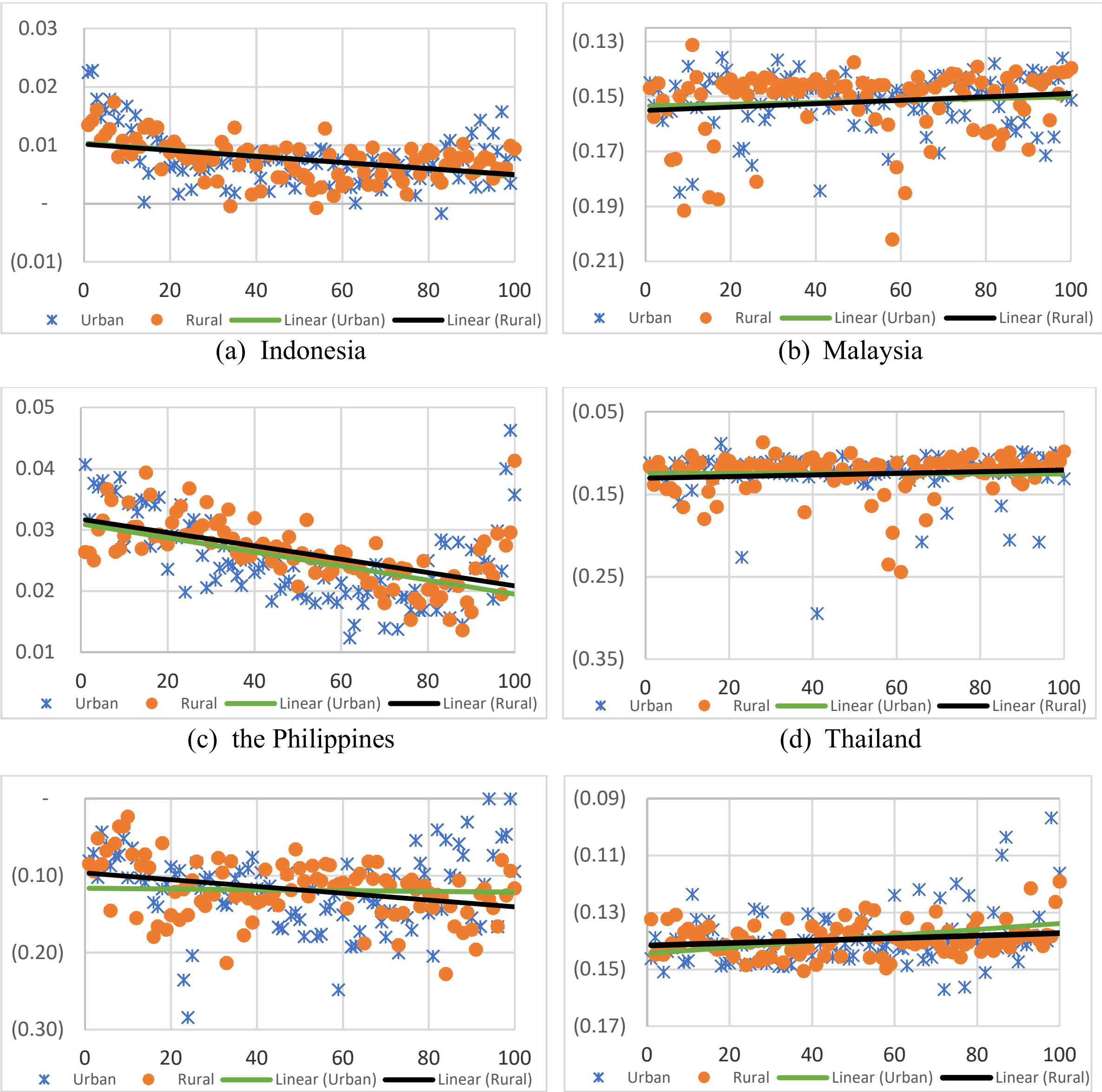
Another way to examine the difference in poverty incidence reduction is through income distribution changes per percentile. Figure 3 exhibits income per capita distribution changes for SIM2 compared to SIM1. It is distributed across 100 different types of household in urban and rural areas based on population percentile. In general, countries with relatively smaller reductions in poverty incidence compared to SIM1 such as in Vietnam, Thailand, and Malaysia, have negative values in income distribution changes across household percentiles. On the other hand, Indonesia and the Philippines, that have relatively smaller differences in income distribution between SIM2 and SIM1, have a positive difference in income distribution changes. Nonetheless, these differences in income distribution changes are relatively small and hence have less impact on poverty reduction in SIM2.

The pattern of income distributions is also noticeable across ASEAN countries. Vietnam, the Philippines, and Indonesia exhibit progressive patterns in the urban and rural area. While Malaysia and Thailand have slightly regressive patterns. The progressive income distribution pattern is preferable since it indicates that the poorer household gets higher-income changes compared to the richer household. Nonetheless, even with progressive income distribution pattern in most of ASEAN member countries, it is not sufficient to reduce more poverty incidence compared to SIM1 due to the small magnitude of the sectoral impacts.

In terms of the income flow in an economy, each country has its characteristics, depends on the structure of the economy. For example, East Asia IRSAM indicates that the urban and rural households in Vietnam obtain their incomes most likely from skilled and unskilled labours by more than 62 per cent. Sectoral outputs changes in Figure 2 indicate that due to increasing in the renewable electricity outputs in SIM2, there is a relatively small increase in the primary sectors such as farming and fishing sector by around 0.1 per cent. Developing other renewables such as hydropower and solar power, on the other hand, reduces the sectoral outputs significantly, in particular in the financial services sectors. Since skilled labour income comes from the financial services sector by more than 15.56 per cent, rich households receive less income due to renewable electricity development. Therefore, increasing renewable electricity output leads to the decreased income of skilled and unskilled labour for almost all simulations. The negative sectoral impacts are outweighed the regressive pattern of income distribution and hence lead to relatively higher poverty incidence for all simulations compared to SIM1.

On the other hand, Indonesia households' income comes mostly from labour by more than 73 per cent, relatively higher compared to Vietnam. Nonetheless, the sectoral output changes have a more significant impact on progressive income distribution pattern. Firstly, increasing renewable electricity leads to an increase in the primary and tertiary sectors'output. In the primary sectors, the incomes are distributed mostly to unskilled labour. In the services sectors such as communication and dwellings, in contrast, are most likely are the source of incomes for skilled labours who usually belong to the rich group households. Therefore, any increase in the renewable electricity output in Indonesia benefits the relatively poor group households and creates a regressive pattern in Indonesia. Nonetheless, amongst other ASEAN countries, the magnitude of the income distribution difference compared to SIM1 in Indonesia are relatively small. As a result, households in Indonesia have relatively unchanged poverty incidences across simulations.

Relatively different to Indonesia, the source of households' income in the Philippines is relatively balanced between labour and capital incomes. For example, East Asia IRSAM indicates that the income from labour is around 49 per cent, while non-labour income from capital, natural resource, and the land is around 47 per cent. In terms of income from sectoral, any increase in the renewable electricity output most likely beneficial for all sectors, in particular fishing and dwelling sectors. Most of the income in these two sectors are distributed to capital through natural resource and capital ownerships. Therefore, even with a progressive income distribution pattern and positive difference in income distribution changes compared to SIM1, the poverty incidence is barely changed in the Philippines.



(a) Indonesia (b) Malaysia

(c) the Philippines (d) Thailand

(e) Vietnam (f) Rest of ASEAN

Figure 3. Income Distribution Difference of SIM2 to SIM1 (percentage changes)

5.3 Environmental impacts

Even though there are positive macroeconomic impacts of electricity generation from both fossil fuel and renewable energy, any intensive usage of fossil fuel in the electricity sector will increase the carbon emissions across ASEAN countries. One way to keep on higher GDP while keeping carbon emissions low is to develop more renewable electricity sources. SIM2, SIM3, and SIM4 results indicate that renewable electricity development does lead to lower carbon emissions (Table 6). In general, a different type of renewable energy has different impacts on carbon emissions. For example, solar power development in most ASEAN countries induces slightly lower carbon emissions compared to SIM1. In Indonesia, increasing solar power reduces carbon emissions by around 0.25 percentage changes lower than SIM1, while increasing wind and hydropower reducing carbon emissions relative to SIM1 at approximately 0.21 and 0.23 percentage changes respectively. Vietnam, on the hand, has a relatively higher reduction in carbon emissions that are more than five times of Indonesia. Similar results can be found for other ASEAN countries, that developing solar power electricity does reduce carbon emission relatively larger than SIM1's reduction in carbon emission.

Table 6. Changes in Carbon Emissions

	SIM1 (mt CO2)	SIM2 (% change)	SIM3 (% change)	SIM4 (% change)
Indonesia	259.37	-0.21	-0.23	-0.25
Malaysia	94.77	-0.42	-0.33	-0.42
Philippines	35.14	-0.50	-0.47	-0.50
Singapore	23.81	-0.17	-0.17	-0.11
Thailand	149.27	-0.54	-0.55	-0.55
Vietnam	77.44	-1.31	-1.01	-1.66
Rest of ASEAN	13.78	-0.32	-0.15	-0.22

Notes: mt CO_2 = a million tonnes of CO_2; column SIM1 shows the carbon emissions of ASEAN countries under SIM1. Columns SIM2, SIM2, SIM3 show how much ASEAN countries' carbon emissions be different compared to those under SIM1. Therefore, % Changes for SIM2, SIM3, and SIM4 indicate percentage changes relative to the SIM1; SIM1 simulates 10 per cent increase of fossil fuel electricity sector's output, SIM2 simulates increase of wind power electricity sector's output at a similar value of SIM1, SIM3 simulates increase of hydropower electricity sector's output at a similar value of SIM1, SIM4 simulates increase of solar power electricity sector's output at a similar value of SIM1.

Energy mix in the electricity sector and carbon emissions during electricity generation could be one possible explanation of different macroeconomics and environmental impacts on each ASEAN country. From Table 2, it is clear that the majority of ASEAN countries utilised fossil fuel as the main engine to produced electricity and it is expected that there are higher carbon emissions amongst ASEAN countries. Further, Table 7 reveals that Indonesia has the most contribution of carbon emissions from coal by almost 70 per cent. The Philippines and Vietnam have a relative balance contribution either from coal or gas manufacture distribution sector. Thailand has a dominant contribution from gas manufacture distribution only. In short, Table 7 indicates that the energy mix in producing electricity is important. As countries have more diversification in electricity sources, in particular a balance between renewable energy and fossil fuel, such as Vietnam and the Philippines, can reduce carbon emissions more than a country that has a heavy reliance on fossil fuel electricity such as Indonesia.

Table 7. Carbon Emissions of the electricity sector

	IDN	MYS	PHL	SGP	THA	VNM	XSE
Total Carbon Emissions (in million tonne CO_2)							
	124.64	42.73	16.53	3.47	50.02	35.47	4.76
Carbon Emissions Contribution (in %)							
Coal	69.66	14.99	49.63	0.00	33.70	55.51	14.06
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas	0.78	0.01	0.02	0.00	0.01	0.07	54.44
Petroleum coal products	15.14	11.53	8.65	99.72	2.31	1.38	6.12
Gas manufacture distribution	14.42	73.47	41.70	0.28	63.98	43.05	25.39
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Notes: IDN= Indonesia; MYS= Malaysia; PHL= the Philippines; SGP=Singapore; THA=Thailand; VNM= Vietnam; XSE = Rest of ASEAN. Source: GTAP Database Version 9, the base year 2011.

6. Conclusions

Utilising an East-Asia Inter-Regional Social Accounting Matrices, which contains renewable electricity power generation accounts, this paper observes the socio-economic and environmental impacts of the rise of renewable energy share in ASEAN countries. This paper simulated the impacts of increasing electricity output from fossil fuels in comparison with that from renewable sources such as wind, hydro and solar. To achieve this goal, this paper conducted three analysis on IRSAM. Firstly, an inter-regional CFPM method on the East Asia IRSAM measuring the impact of electricity outputs on economic activities and income for the households. Secondly, this paper utilises a household income microsimulation model to translate the macroeconomic impacts of the increasing electricity sector's output into the income of various household groups and computed poverty incidence for each ASEAN countries. Finally, this paper calculated the carbon emission changes as a side effect of increasing the electricity sector's output.

There are four simulations in this paper. The first simulation is the baseline simulation representing a business as usual situation which assumes that there is an increase in fossil fuel electricity output by 10 per cent. The last three simulations simulate an increase in wind, hydro, and solar electricity output as much as the value of output at the first simulation. From comparing results from the other simulation to the baseline simulation, several conclusions can be drawn.

This paper finds that renewable electricity development could be a way to induce higher GDP while keeping carbon emissions relatively low. It is predicted that if the increase in electricity output comes from the renewable electricity generation the GDP will be at least 0.1 per cent higher than that if the increase in electricity output comes from the fossil oil electric power generation.

Renewable electricity development can outperform fossil fuel development since it allows a disperse spillover of the shock into non-energy sectors such as primary sector (farming and fishing) and tertiary sectors (financial services and dwelling). In this case, backward and forward linkages across sectors in an economy do matter.

Nonetheless, this paper finds that renewable electricity development leads to lower rate of poverty incidence reduction compared to that of fossil fuel electricity. This paper argues that the initial level of income per capita, income distribution pattern, and income flow in an economy matter in determining the reduction of poverty. If a country has a high income per capita, it is expected to have a lower poverty reduction, vice versa. Also, this paper finds that the main contributor of poverty reduction is non-energy sectoral outputs' changes that contribute more on the poverty reduction than energy sectoral outputs changes since it allows more income being distributed across the economy.

In the case of Indonesia, a combination of a relatively higher initial income per capita and fewer impacts on the non-energy sector lead to less poverty reduction. Vietnam and the Philippines, on the other hand, have relatively lower initial income per capita and higher impacts on sectoral output and provide more income to the households and more poverty reductions.

The policy implications of this paper are as follows. Developing renewable energy as an alternative source to generate electricity is a legitimate way for ASEAN countries to address socio-economic and environmental angles such as higher aggregate and sectoral outputs, reducing carbon emissions, and reducing poverty incidence. Nonetheless, this paper does not estimate the cost to construct and build different types of power plant for renewable energy. Also, this paper assumes that there is an under-capacity in the economy, such that there is no substitution across sectors. Another caveat is that it is assumed that the price is fixed. However, this paper shows that by utilising a simple general equilibrium model such as IRSAM could give insightful findings, in particular socio-economic and environmental impacts.

References

ACE. 2015. “ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025.”

ASEAN. 2020. “The ASEAN Declaration (Bangkok Declaration).” Available at: https://asean.org/the-asean-declaration-bangkok-declaration-bangkok-8-august-1967/ [Accessed January 15, 2020].

Bourguignon, F., and M. Bussolo. 2013. *Income distribution in computable general equilibrium modeling*. Elsevier. Available at: http://dx.doi.org/10.1016/B978-0-444-59568-3.00021-3.

Corona, B., C. de la Rúa, and G. San Miguel. 2016. “Socio-economic and environmental effects of concentrated solar power in Spain: A multiregional input output analysis.” *Solar Energy Materials and Solar Cells* 156:112–121. Available at: http://dx.doi.org/10.1016/j.solmat.2016.03.014.

Gibon, T., E.G. Hertwich, A. Arvesen, B. Singh, and F. Verones. 2017. “Health benefits, ecological threats of low-carbon electricity.” *Environmental Research Letters* 12(3).

Goh, T., B.W. Ang, and X.Y. Xu. 2018. “Quantifying drivers of CO2 emissions from electricity generation – Current practices and future extensions.” *Applied Energy* 231(May):1191–1204.

GTAP. 2019. “GTAP Data Bases: Two Concordances.” Available at: https://www.jgea.org/databases/contribute/concordinfo.asp [Accessed January 15, 2020].

Hartono, D., and B.P. Resosudarmo. 2008. “The economy-wide impact of controlling energy consumption in Indonesia: An analysis using a Social Accounting Matrix framework.” *Energy Policy* 36(4):1404–1419.

IEA. 2020. “Data & Statistics.” Available at: https://www.iea.org/data-and-statistics [Accessed January 10, 2020].

ILO. 2012. *International Standard Classification of Occupations ISCO-8*. Geneva: International Labour Office.

IRENA. 2018. *Renewable Energy Market Analysis: Southeast Asia*. Available at: www.irena.org.

Lewis, B.D., and E. Thorbecke. 1992. “District-level economic linkages in Kenya: Evidence based on a small regional social accounting matrix.” *World Development* 20(6):881–897.

Novan, K. 2015. “Valuing the wind: Renewable energy policies and air pollution avoided.” *American Economic Journal: Economic Policy* 7(3):291–326.

Nurdianto, D.A., and B.P. Resosudarmo. 2016. “Economy-wide Impact of a Carbon Tax in ASEAN.” *Journal of Southeast Asian Economics* 33(1):1–15.

Peters, J.C. 2016. “The GTAP-Power Data Base: Disaggregating the Electricity Sector in the

GTAP Data Base." *Journal of Global Economic Analysis* 1(1):209–250.

Resosudarmo, B.P., D.A. Nurdianto, and D. Hartono. 2009. "The Indonesian Inter-Regional Social Accounting Matrix for Fiscal Decentralisation Analysis." *Journal of Indonesian Economy and Business* 24(2):145–162.

Resosudarmo, B.P., and E. Thorbecke. 1998. "Reducing the number of pesticide-related illnesses: the impact on household incomes in Indonesia." *Bulletin of Indonesian Economic Studies* 34(2):143–157.

Resosudarmo, B.P., and E. Thorbecke. 1996. "The impact of environmental policies on household incomes for different socio-economic classes: The case of air pollutants in Indonesia." *Ecological Economics* 17(2):83–94.

Richard, H.A., and A. Ahsan. 2014. *Managing International Migration for Development in East Asia* H. A. Richard and A. Ahsan, eds. Washington, DC : World Bank Group: World Bank Publications.

Thorbecke, E., and H.S. Jung. 1996. "A multiplier decomposition method to analyze poverty alleviation." *Journal of Development Economics* 48(2):279–300.

World Bank. 2019. "Global Poverty Line Update." Available at: http://www.worldbank.org/en/topic/poverty/brief/global-poverty-line-faq [Accessed May 21, 2019].

Yusuf, A.A., and B.P. Resosudarmo. 2015. "On the distributional impact of a carbon tax in developing countries: the case of Indonesia." *Environmental Economics and Policy Studies* 17(1):131–156.

Supplement A. Derivation of the Constrained Fixed Price Multiplier

This section explains in detail on the derivation of the Constrained Fixed Price Multiplier following Hartono & Resosudarmo (2008); Resosudarmo & Thorbecke (1996); and Lewis & Thorbecke (1992).

	Region 1	Region 2	Region 3	ROW	TOTAL
Region 1	A_{NC}^{11}	Q^{12} A_{NC}^{12}	A_{NC}^{13}	X_{NC}^{1}	Y_{NC}^{1}
Region 2	R^{21} A_{NC}^{21}	A_C^{22} R^{22} Q^{22} A_{NC}^{22}	R^{23} A_{NC}^{23}	X_C^2 X_{NC}^2	Y_C^2 Y_{NC}^2
Region 3	A_{NC}^{31}	Q^{32} A_{NC}^{32}	A_{NC}^{33}	X_{NC}^{3}	Y_{NC}^{3}
ROW	l^1	l^2	l^3	t	Y_E
TOTAL	$(Y_{NC}^1)'$	$(Y_C^2)'$ $(Y_{NC}^2)'$	$(Y_{NC}^3)'$	$(Y_E)'$	

Figure S1. Structure of 3 Regions IRSAM with Constrained Sector

Figure S1 is a simplification of the Inter-regional Social Accounting Matrix for three regions only. Total incomes in Region 1 and Region 3 are denoted by Y_{NC}^1 and Y_{NC}^3 respectively. While Region 2's total income consists of total income vectors of the constrained sector in Region 2 (Y_C^2) and total income vectors of the non-constrained sector in Region 2 (Y_{NC}^2). Term A_C^{22} is a matrix of average expenditure propensities of the constrained sector in Region 2. Similarly, term A_{NC}^{11}, A_{NC}^{22}, and A_{NC}^{33} are matrices of average expenditure propensities of non-constrained the sector in Region 1, Region 2, and Region 3 respectively. Similarly, terms A_{NC}^{12}, A_{NC}^{13}, A_{NC}^{21}, A_{NC}^{23}, A_{NC}^{31}, and A_{NC}^{32} are matrices of non-constrained average expenditure propensities for Region 1, Region 2, and Region 3. Terms l^1 , l^2 , and l^3 are leakages while X_{NC}^1, X_C^2, X_{NC}^2, and X_{NC}^3 are vectors of injection. Finally, t is a vector of exogenous.

Figure S1 can be expressed in the matrices operation as follow.

$$d\begin{bmatrix} Y_{NC}^1 \\ Y_C^2 \\ Y_{NC}^2 \\ Y_{NC}^3 \end{bmatrix} = \begin{bmatrix} A_{NC}^{11} & Q^{12} & A_{NC}^{12} & A_{NC}^{13} \\ R^{21} & A_C^{22} & R^{22} & R^{23} \\ A_{NC}^{21} & Q^{22} & A_{NC}^{22} & A_{NC}^{23} \\ A_{NC}^{31} & Q^{32} & A_{NC}^{32} & A_{NC}^{33} \end{bmatrix} d\begin{bmatrix} Y_{NC}^1 \\ Y_C^2 \\ Y_{NC}^2 \\ Y_{NC}^3 \end{bmatrix} + d\begin{bmatrix} X_{NC}^1 \\ X_C^2 \\ X_{NC}^2 \\ X_{NC}^3 \end{bmatrix} \tag{S1}$$

The matrices in Equation S1 can be transformed into a linear system of equations as presented in Equation S2, S3, S4, and S5.

$$dY_{NC}^1 = A_{NC}^{11}\, dY_{NC}^1 + Q^{12}\, dY_C^2 + A_{NC}^{12}\, dY_{NC}^2 + A_{NC}^{13}\, dY_{NC}^3 + dX_{NC}^1 \tag{S2}$$

$$dY_C^2 = R^{21}\, dY_{NC}^1 + A_C^{22}\, dY_C^2 + R^{22}\, dY_{NC}^2 + R^{23}\, dY_{NC}^3 + dX_C^2 \tag{S3}$$

$$dY_{NC}^2 = A_{NC}^{21}\, dY_{NC}^1 + Q^{22}\, dY_C^2 + A_{NC}^{22}\, dY_{NC}^2 + A_{NC}^{23}\, dY_{NC}^3 + dX_{NC}^2 \tag{S4}$$

$$dY_{NC}^3 = A_{NC}^{31}\, dY_{NC}^1 + Q^{32}\, dY_C^2 + A_{NC}^{32}\, dY_{NC}^2 + A_{NC}^{33}\, dY_{NC}^3 + dX_{NC}^3 \tag{S5}$$

Rearranging Equation (S2) up to Equation (S5)

$$(I - A_{NC}^{11})\, dY_{NC}^{1} = Q^{12}\, dY_{C}^{2} + A_{NC}^{12}\, dY_{NC}^{2} + A_{NC}^{13}\, dY_{NC}^{3} + dX_{NC}^{1} \qquad \text{(S2a)}$$

$$dX_{C}^{2} = dY_{C}^{2} - R^{21}\, dY_{NC}^{1} - A_{C}^{22}\, dY_{C}^{2} - R^{22}\, dY_{NC}^{2} - R^{23}\, dY_{NC}^{3} \qquad \text{(S3a)}$$

$$(I - A_{NC}^{22})\, dY_{NC}^{2} = A_{NC}^{21}\, dY_{NC}^{1} + Q^{22}\, dY_{C}^{2} + A_{NC}^{23}\, dY_{NC}^{3} + dX_{NC}^{2} \qquad \text{(S4a)}$$

$$(I - A_{NC}^{33}) dY_{NC}^{3} = A_{NC}^{31}\, dY_{NC}^{1} + Q^{32}\, dY_{C}^{2} + A_{NC}^{32}\, dY_{NC}^{2} + dX_{NC}^{3} \qquad \text{(S5a)}$$

Rearranging Equation S2a, S3a, S4a, and S5a:

$$(I - A_{NC}^{11})\, dY_{NC}^{1} - A_{NC}^{12}\, dY_{NC}^{2} - A_{NC}^{13}\, dY_{NC}^{3} = dX_{NC}^{1} + Q^{12}\, dY_{C}^{2} \qquad \text{(S2b)}$$

$$-R^{21}\, dY_{NC}^{1} - R^{22}\, dY_{NC}^{2} - dX_{C}^{2} - R^{23}\, dY_{NC}^{3} = -(I - A_{C}^{22})\, dY_{C}^{2} \qquad \text{(S3b)}$$

$$-A_{NC}^{21}\, dY_{NC}^{1} + (I - A_{NC}^{22})\, dY_{NC}^{2} - A_{NC}^{23}\, dY_{NC}^{3} = Q^{22}\, dY_{C}^{2} + dX_{NC}^{2} \qquad \text{(S4b)}$$

$$-A_{NC}^{31}\, dY_{NC}^{1} - A_{NC}^{32}\, dY_{NC}^{2} + (I - A_{NC}^{33}) dY_{NC}^{3} = Q^{32}\, dY_{C}^{2} + dX_{NC}^{3} \qquad \text{(S5b)}$$

Translate Equation S2b, S3b, S4b, and S5b into matrices form:

$$\begin{bmatrix} (I - A_{NC}^{11}) & -A_{NC}^{12} & 0 & -A_{NC}^{13} \\ -R^{21} & -R^{22} & -I & -R^{23} \\ -A_{NC}^{21} & (I - A_{NC}^{22}) & 0 & -A_{NC}^{23} \\ -A_{NC}^{31} & -A_{NC}^{32} & 0 & (I - A_{NC}^{33}) \end{bmatrix} d \begin{bmatrix} Y_{NC}^{1} \\ Y_{NC}^{2} \\ X_{C}^{2} \\ Y_{NC}^{3} \end{bmatrix} = \begin{bmatrix} I & Q^{12} & 0 & 0 \\ 0 & -(I - A_{C}^{22}) & 0 & 0 \\ 0 & Q^{22} & I & 0 \\ 0 & Q^{32} & 0 & I \end{bmatrix} d \begin{bmatrix} X_{NC}^{1} \\ Y_{C}^{2} \\ X_{NC}^{2} \\ X_{NC}^{3} \end{bmatrix}$$

Then, the solution for Constrained Fixed Price Multiplier with three regions is:

$$d \begin{bmatrix} Y_{NC}^{1} \\ Y_{NC}^{2} \\ X_{C}^{2} \\ Y_{NC}^{3} \end{bmatrix} = \begin{bmatrix} (I - A_{NC}^{11}) & -A_{NC}^{12} & 0 & -A_{NC}^{13} \\ -R^{21} & -R^{22} & -I & -R^{23} \\ -A_{NC}^{21} & (I - A_{NC}^{22}) & 0 & -A_{NC}^{23} \\ -A_{NC}^{31} & -A_{NC}^{32} & 0 & (I - A_{NC}^{33}) \end{bmatrix}^{-1} \begin{bmatrix} I & Q^{12} & 0 & 0 \\ 0 & -(I - A_{C}^{22}) & 0 & 0 \\ 0 & Q^{22} & I & 0 \\ 0 & Q^{32} & 0 & I \end{bmatrix} d \begin{bmatrix} X_{NC}^{1} \\ Y_{C}^{2} \\ X_{NC}^{2} \\ X_{NC}^{3} \end{bmatrix}$$

Supplement B. Microsimulation for Poverty Incidence

There are four main sections to compute the microsimulation. Firstly, extracting necessary data from the survey data. Secondly, computing changes of outputs as well as income in inter-regional SAM. Thirdly, aggregating the 57 sectors of GTAP into 10 sectors for simplicity and accommodating the different level of aggregation across survey data in Indonesia, Thailand, Vietnam, and the Philippines. Finally, the last section is the microsimulation computation.

B.1 Extracting Necessary Survey Data

This paper needs to extract some data from the household level survey of each country. The first one, relates to the location of the household, whether it is located in urban or rural areas. The location is essential since the inter-regional IRSAM disaggregates household into urban and rural households.

Secondly, income data from the skilled and unskilled labour force. While urban and rural classification is clearly defined in the survey, the skilled and unskilled labour has not. This paper defines skilled labour as those who finished secondary education. Based on ILO (2012) on the International Standard Classification of Occupations ISCO-8, unskilled is defined as not finished secondary education. This report argues that formal education and training are the measurements of skill level indication. Similarly, Richard and Ahsan (2014) define unskilled as having a secondary education or less.

Also, this paper generates sectoral dummy for labour in households. In particular, this paper generates a dummy variable for each worker in each sector to obtain the sectoral labour share for both skilled and unskilled labours.

Total income for each household is computed on a monthly/yearly basis which covers income from worker and business. The number of household member counts for one that still lives in the household only. The income per capita is simply the total income per household divided by the number of a household member.

Finally, the observations are categorised into 100 types of the household for both in urban and rural areas based on several observations. There is a probability weight for each household. This paper expands the dataset based on the number of a household member and household weight. It is necessary since this paper aims to disaggregate the observation based on several observations. Such that, each group contains a similar number of observations.

From this step, the number of labour by sectoral and skill as well as a share of income can be constructed.

B.2 Changes in the Output from Inter-Regional SAM (IRSAM)

In IRSAM, the total payment of activities to production factor should be equal to the total income of all institutions. For example, Table S1 and Table S2 present the accounting identity between payment to production factor and institutions income in Indonesia based on IRSAM. In general, the payment from activities is around 807 Billion USD which should be equal to the income of the institutions. The labour income only goes to the households, while for other production factors are distributed to other institutions such as government as well as firm.

Table S1. Payment to Production Factor by Simplified Activities (in Million USD)

Production Factors	Agriculture & Mining	Manufacture	Services	Total
Land	42,652	-	-	42,652
Unskilled Labour	50,140	71,779	140,578	262,496
Skilled Labour	2,466	12,198	64,723	79,387
Capital	74,368	97,899	221,416	393,683
Nat Resources	29,584	-	-	29,584
TOTAL	**199,210**	**181,877**	**426,717**	**807,803**

Table S2. Source of Income by Institution (in Million USD)

Institutions	Land	Unskilled Labour	Skilled Labour	Capital	Nat. Resource	Total
Urban HH	7,060	144,373	43,663	45,403	4,897	245,397
Rural HH	5,777	118,123	35,724	37,148	4,007	200,779
Firm	25,903			275,025	17,967	318,895
Government	3,912			36,107	2,713	42,732
TOTAL	**42,652**	**262,496**	**79,387**	**393,683**	**29,584**	**807,803**

The expenditure of production activities to the production factors as defined in Equation S7.

$$F = \sum_p \sum_q F_q^p \qquad \text{(S7)}$$

where F_q^p denotes production factor types p for sector q, p={unskilled labour, skilled labour, land, capital, natural resources}, and $q = 1,2,3,\ldots,57$ are sectors in IRSAM.

Let r is the institutions' type, r ={urban household, rural household, firm, and government}. Source of income for institutions covers labour v={unskilled and skilled} and non-labour w={land, natural resources, and capital}, where v and w are subsets of p. While it is assumed that all income from labour solely belongs to the household as shown in Table S2, income from non-labour is shared among institutions. The income of the institutions in IRSAM is:

$$I = \sum_r I^r = \sum_r \sum_v \alpha^r L_v^r + \sum_r \beta^r CAP^r + \sum_r \gamma^r NR^r + \sum_r \gamma^r Ln^r \qquad \text{(S8)}$$

where L_v^r is labour income from labour type v in institution type r, CAP is income from the capital while NR is income from natural resources, and Ln is income from land. Terms α, β, and γ are values between zero and one and represents a portion of income belong to the institutions r. Thus, natural resources and land have similar proportion in IRSAM.

Let simplify Equation S8 by assuming that there is a non-labour income which is a summation of income from non-labour such as land, natural resources, and capital.

$$I = \sum_r I^r = \sum_r \sum_v \alpha^r L_v^r + \sum_r \delta^r NL^r \qquad \text{(S9)}$$

Where δ^r and NL^r are the share of income from the non-labour and the total value of non-labour income respectively. Equation S7 should be equal to Equation S9 to satisfy accounting balancedness of Table S1 and Table S2.

For each ASEAN member country, there are different values of α^r and δ^r. For instances, for Indonesia, the value of α^r equals to 0.55 and 0.45 for urban and rural households respectively. For other institutions parameter α^r is zero as mentioned earlier. For non-labour income, δ^r are 0.12 and 0.10 for urban and rural households. Parameter δ^r is dominantly owned by the firm which is approximately 0.68 while the government only receive 0.09.

Another feature of IRSAM is Equation S8 can be expressed as a product of multiplication between IRSAM endogenous Matrix A and total sectoral output. Let $\boldsymbol{S}$ is the square matrix of IRSAM with ixj dimension, where $i = j$. Endogenous Matrix **A** is simply defined as $a_{ij} = \frac{s_{ij}}{\sum_i s_{ij}} = \frac{s_{ij}}{S_j}$.

Then $s_{ij} = a_{ij}S_j$ (S10)

where a_{ij} is the element of Matrix A at row i and column j; S_j is the total value of column j.

If there is an exogenous shock which causes the new value of each sectoral output becomes S'_j. Then, the new value of s_{ij}, s'_{ij}, can be computed as

$$s'_{ij} = a_{ij}S'_j \quad \text{(S11)}$$

B.3 Aggregating industry/sector on GTAP and survey data

Each survey data used for microsimulation have different sectoral disaggregation. SUSENAS, for instance, has 19 distinct sectors based on the 2009 *Klasifikasi Baku Lapangan Usaha Indonesia* (KBLI)-Indonesia Industrial Standard Classification. This 2009 KBLI is restructured following ISIC Rev.4. In the case of Thailand, SES uses the NSO Standard Industrial Classification of All Economic Activities NSIC 2009 which provides detail classification of industry up to 4 digits. VHLSS uses the industry code based on the Prime Minister Decision No.10/2007/QD-TTg on the List of Vietnam's Economic Sector[5]. The industry code disaggregates into 3 digits classification. While LFS for the Philippines uses 4 digits of the Philippine Standard Industry Classification (PSIC) which is an adaption of the United Nations International Standard Industrial Classification[6].

For each survey data, the industry/sector code is needed to be aggregated. The GTAP sectoral classification is aggregated from 57 sectors in GTAP into 10 sectors. Similarly, the aggregation also is done for survey datasets for Indonesia, Thailand, Vietnam, and the Philippines. The industry/sector code concordancy is relatively straight forward since this paper only extracts the industry/sector code at most 2 digits. This paper utilises sectoral concordancy guidance which is provided by World Integrated Trade Solution[7]. WITS provides concordance tables based on HS classification for both CPC and ISIC Rev3 as used in GTAP. The sectoral

[5] General Statistics Office. (2010), "Decision on the Vietnam Household Living Standards Survey (VHLSS) 2010", Hanoi

[6] Philippine Statistics Authority. (2009), "2009 Philippine Standard Industrial Classification" and Philippine Statistics Authority. (2019), "Technical Notes on the Labor Force Survey | Philippine Statistics Authority".

[7] World Integrated Trade Solution. (2019), "WITS - Concordance".

classification in GTAP can be converted into ISIC Rev3 Classification. Then since for each survey data, this paper matches the ISIC Classification into each country dataset. For Indonesia and the Philippines are relatively simple since both countries adopt ISIC as well. Also, even though Vietnam and Thailand classified under different coding, apparently the classification still similar to ISIC.

B.4 Microsimulation

Taking the distinct features of IRSAM as presented in Equation S10 and Equation S11, microsimulation can be done by firstly computing the value of Average Propensity Expenditure element of row i and column j, a_{ij}, for production activities payment to the production factors in Indonesia. Then, the new total sectoral output S_j' is obtained from the simulation by using CFPM. The new block of production factor payment, hence, can be computed by utilising Equation S11.

The next step is to distribute the total value of each production factor income into institutions based on α and δ parameter values in Equation S9. As a result, the new block of institution income can be constructed. In the baseline, the value should be equal to the IRSAM value.

By incorporating the income share which is obtained from survey data, this paper disaggregates the value of household income, for both urban and rural into 100 different types of household. Both labour and non-labour income utilise similar income share as a control for sectoral income.

$$H_c^{ur} = \sigma_c^{ur} sl^{ur} \sum_v \sum_q \frac{N_c^{v,q}}{\sum_c N_c^{v,q}} lb^{v,q} + \varsigma_c^{ur}\, inc\_sh_c^{ur} sh^{ur} \sum_w \sum_q nlb^{w,q} \qquad \text{(S12)}$$

where H_c^{UR} is income for the c percentile household in the urban/rural area. This paper disaggregates household group both in urban and rural into 100 groups, based on population percentile (Nurdianto and Resosudarmo 2016). Superscript q denotes sector in a region. Similary superscripts v defined as labour income type (skilled and unskilled labour) and superscript w denotes non-labour income type (land, natural resources, and capital). Terms σ_c^{ur} and ς_c^{ur} are scaling factors to adjust the value of total labour income and non-labour income according to the IRSAM value. Terms sl^{ur} and sh^{ur} are the share of labour and non-labour factor incomes for urban and rural households. To distribute sectoral factor income, this paper utilises sectoral labour share for labour income and income share based on survey data for non-labour income. Sectoral labour share term is constructed as follow. Term $N_c^{v,q}$ denotes the number of labour type v by sector q in household c. Therefore, term $\frac{N_c^{v,q}}{\sum_c N_c^{v,q}}$ is simply sectoral labour share of household percentile c. Income share term ($inc\_sh_c^{ur}$) is simply a percentage of income based on population percentile. Finally, term $lb^{v,q}$ is labour income type v in sector q. Similarly, term $nlb^{w,q}$ denotes non-labour income for w type from sector q.

The rest is to compute poverty incidence. To measure poverty rate, this paper uses poverty incidence which is done by utilising linear proximation of the poverty rate, similar to Yusuf and Resosudarmo (2015). Let z_c is the real income per capita of household percentile c and z_p is poverty line which lies between two levels of real income per capita. The poverty rate is:

$$p(z_c, z_p) = \max\{c \mid z_c < z_p\} + \nabla c \qquad \text{(S13)}$$

Term $\max\{c|\, z_c < z_p\}$ represents the number of households below the poverty line, while

$$\nabla \mathrm{c} = \frac{z_p - \max\{z_c|z_c < z_p\}}{\min\{z_c|z_c > z_p\} - \max\{z_c|z_c < z_p\}} \,.\min\{c|\, z_c > z_p\} - \max\{c|\, z_c < z_p\} \qquad \text{(S14)}$$

where $\min\{z_c \mid z_c > z_p\}$ is the minimum real income per capita which is above to the poverty line; $\max\{z_c \mid z_c < z_p\}$ is the maximum real income per capita which is below to the poverty line; and $\min\{c|\, z_c > z_p\}$ is the number of household above the poverty line.

The change in the poverty rate is defined in Equation S15.

$$\Delta p = p(z'_c, z'_p) - p(z_c, z_p) \qquad \text{(S15)}$$

where z'_c and z_c is the real income per capita based on simulations results and baseline respectively. Also, the poverty line is 1.25 USD in 2011 as defined by the World Bank (2019b).