Sustainability, inclusive wealth, and energy:

Local and global analysis

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Abstract

To understand the trajectory of sustainability, it is important to measure historical and future projections of productive capital that contribute to well-being for the local and global scope. Compared to other alternatives, Inclusive Wealth *(IW)* offers a better approach for assessing sustainability, since it provides a comprehensive measurement of stock variables which are related to the potential intergenerational well-being. The *IW* framework, which includes human, produced, and natural capital, is also able to portray the whole capacity of a country's assets that serve the provision toward human well-being.

Extending the *IW* concept for local and global scope, this thesis is divided into five chapters. Chapter 1 presents the background and objectives of the study. Methodology and datasets of the study are explained in Chapter 2. Focusing on Indonesia, chapter 3 explores sustainability, economic growth, and energy-related issue. Extending the framework utilized in Indonesia scope, chapter 4 analyzes the global scope of sustainability. Chapter 5 consist of conclusions, implications and future research.

In the Indonesia scope, sustainability, economic growth, and energy-related issue in the country were explored. The first part of the Indonesia study uses *IW* framework to explore the nexus between sustainability and economic growth in the country. It is found that Indonesia's inclusive wealth per capita has been negative, the GDP per capita growth in Indonesia does not necessarily indicate sustainability. The depreciation of both renewable and non-renewable natural capital is driving the decline in wealth per capita. The second part of the Indonesia scope analyzes the effects of economic growth, urbanization, industry, and trade openness on coal consumption in Indonesia using the autoregressive distributed lag. The empirical evidence showed that economic growth, urbanization and trade openness increase coal consumption while decreasing share of secondary industry reduce it. The third part of the Indonesia study examines the characteristics of the Indonesian energy matrix and its evolution in the household sector alongside the impact of kerosene to the Liquid Petroleum Gas conversion program to the Indonesian emissions change. Conducting the decomposition analysis, it is found that the energy mix and carbon intensity effect, which reflects the conversion of kerosene to LPG, contributes to reducing direct emissions with limited effect. High share growth of coal in electricity generation led to increasing indirect emissions for the study period.

Shifting to the global scope, a study for 140 countries is performed by extending the framework utilized in Indonesia scope. The first feature of this global scope analyzes the linkage between economic development and environmental quality from the sustainability framework. Utilizing a pooled mean group estimator analysis, it is found that the beneficial impact of the economy only occurs temporarily, since the strong link between environmental degradation and economic development reappear once the second turning point is achieved. Productivity and efficiency measure by using natural capital of inclusive wealth were studied as the second objectives. Applying a weighted Russel directional distance approach, it is found that natural capital remains significant burdens for many countries' performance, especially for countries with resource-driven economies. The adjustment to a conventional productivity growth measure depends on GDP growth and an endowment growth shift of natural capital relative to other input factors. The third feature of the scope adapts the *IW* framework for understanding long-term global sustainability. It is found that poverty alleviation, demographic changes and human capital investments are effective instruments to attain greater wealth. Furthermore, the scenario that describes a sustainability pathway, which poses the least amount of climate change challenges and substantially reduced reliance on natural resources, is more conducive to increasing wellbeing than the fragmented pathways that result in inequality.

This finding enhances our understanding of how particular countries can measure and manage their sustainability. For Indonesia case, to return to a sustainable growth path, the country must increase its investments to net positive gains at the rate of wealth growth, restrain excessive coal consumption, increasing the share renewable energy in the national energy mix, and intensifying energy efficiency in the household sector. Over the global scope, this finding highlights the importance of managing renewable resources, promoting efficient extraction, and improving education to enhance sustainability.

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1. Introduction

1.1 Sustainability, well-being, and inclusive wealth

Countries need a tool that comprehensively records their wealth to measure the progress towards the Sustainable Development Goals (Dasgupta et al., 2015). To understand the trajectory of sustainability, it is important to measure historical and future projections of productive capital that contribute to well-being. According to Arrow et al. (2012) and Walker et al. (2009), sustainability is the capacity to provide wellbeing to future generations. Wellbeing as a measure of the quality of good life covers income, educational, as well as ecosystem services from nature (Western and Tomaszewski, 2016). To show the relationship between wellbeing, GDP, and inclusive wealth, I present the schematic in figure 1.1.
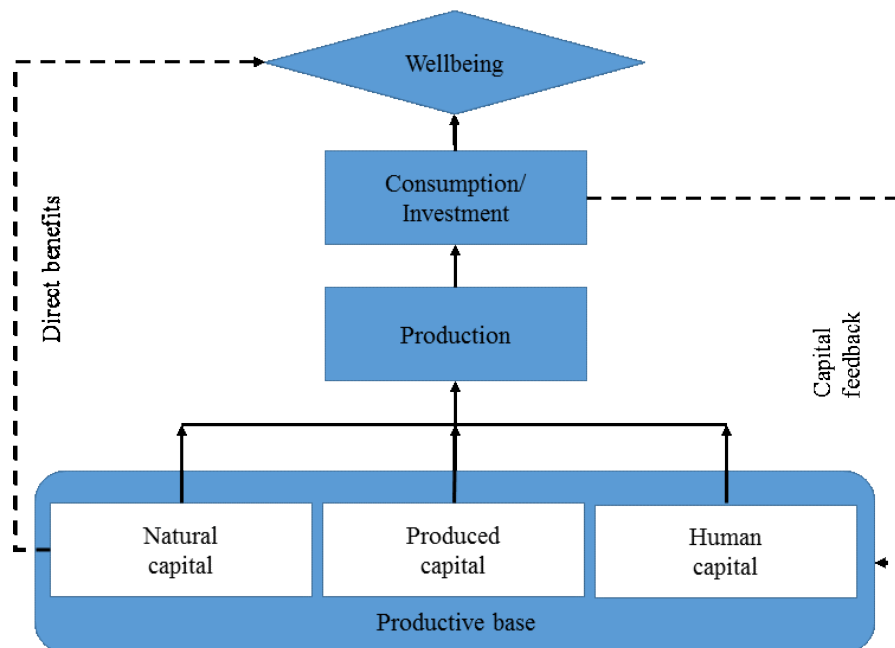
Figure 1. 1 Productive base, GDP, and wellbeing

Source: Adapted from Mumford (2016) and UNU-IHDP (2014).

Compared to other alternatives to GDP, Inclusive Wealth *(IW)* offers a better approach for assessing sustainability, since it provides a comprehensive measurement of stock variables, which are related to the potential intergenerational well-being (Arrow et al., 2012; Collins et al., 2017), and integrates biophysical with social aspects in its accounting system (Fenichel et al., 2016).

1.2 Previous applications review

Having the advantages, the *IW* framework has been widely used for, among others, global sustainability trajectory assessment (Managi and Kumar, 2018). The summary of some previous literature concerning inclusive wealth framework applications is provided in Table 1.1.

Table 1. 1 Summary of inclusive wealth approach implementation

No	References	Application	Periods	Region
1	Collins et al. (2017)	Policy evaluation of electricity infrastructure planning	2000-2013	oil-exporting countries
2	Fujii and Managi (2016)	Urban planning evaluation for sustainable city design	2000-2010	20 Japanese cities
3	Ikeda et al. (2017)	Sustainability of each prefecture in Japan; cost benefit analysis including inclusive wealth	1990–2010	prefectures in Japan
4	Managi and Kumar (2018)	Global retrospective sustainability evaluations	1990-2014	Global scale
5	Pearson et al. (2017)	Regional sustainability measures	1991–2001	Goulburn-Broken Catchment in Australia
6	UNU-IHDP (2014)	Global retrospective sustainability evaluations	1990-2010	Global scale
7	Uehara and Mineo (2017)	Integrates Satoumi, the ecosystem services, and inclusive wealth	1963-2013	Japan's Seto Inland Sea
8	Yoshida et al. (2018)	Comparing local-scale inclusive wealth and national level	1990-2014	Sado Island and Japan
9	Zhang and Sun (2018)	Inclusive wealth approach for measuring ocean wealth	2006-2014	China

It is necessary to study specific country with highly diverse resources such as Indonesia. Supported by economy-boosting commodity prices, Indonesia has become one of the largest low–middle income countries in the world (Basri et al., 2016). In the energy sector of the country, despite its huge renewable-energy potential, the share of fossil fuels is currently approximately 96% of the total primary energy consumption (NEC, 2014). In addition, Indonesia had initiated the massive kerosene to Liquid Petroleum Gas (LPG) conversion program in 2007 which has been considered as the one of the world's largest efforts to promote cleaner cooking fuels (World-Bank, 2013).

However, studies concerning sustainability trajectories most rely on cross-country analysis, only generally inferring countries' trajectories. These studies do not sufficiently assess countries such as Indonesia, which have highly diverse resources including forestry and coal. Considered as the fourth most populous country and major coal exporter, to the best of our knowledge, there have been a lacking of studies on the impacts of the socioeconomics variables to the coal consumption in Indonesia. Furthermore, there have been no comprehensive studies on the impacts of Indonesia's kerosene to LPG conversion program on CO_2 emission change in the household sector.

Over the global scope, it is necessary to measure historical wealth, their relationship with economic growth, and future projections of productive capital that contribute to well-being to understand the sustainability pathway. By-product of economic system such as pollutants returns back to the environmental system. It can degrade the environmental system that reduces its services provided which in turn form part of the natural capital. Numerous efforts for achieving sustainability have led to the relationship between environmental degradation and economic growth. However, from a sustainability perspective, previous studies didn't cover a wide range of natural capital which has as a vital role for creating well-being. Moreover, in productivity measures, only a few studies have incorporated natural capital. These include Murillo-Zamorano (2005), and Brandt et al. (2017) that cover a limited natural capital such as sub-soil assets. In addition, previous studies also did not provide a future path for wellbeing and inclusive wealth.

1.3 Objectives and contributions

From the backdrop, this thesis analyzes sustainability in Indonesia and global scope. For Indonesia context, there are three main objectives of this thesis, to explore the nexus between sustainability and economic growth, to measure the effects of the socioeconomics variables to coal consumption, and to investigate the driving forces of households emissions change in the country. Over the global scope, there are three specific aims of this thesis by covering 140 countries which represent 99 percent of global GDP and 95 percent of the global population. This thesis investigates the linkage between economic development and environmental quality, efficiency and productivity of natural capital, and long-term sustainability measure. By doing the progressive measurement for Indonesia and global contexts, there are specific endowments of this thesis to current empirical research on energy and sustainability study. In summary, the contributions and objectives of this study are presented in table 1.2.

Table 1. 2 Objectives and contributions

No	Objectives	Contributions
Sustainability and energy in Indonesia		
1	Assessing economic growth from a sustainability perspective	Covering Indonesia's specifics natural capital account
2	Discovering the linkage between coal consumption and socioeconomic variables	Account for the presence of two unknown structural breaks in the datasets
3	Investigate the underlying determinant of emissions change alongside efforts to promote a cleaner cooking fuel program	Empirical side of cleaner cooking fuel program: underlying determinant emissions
Sustainability, inclusive wealth and its application (140 countries)		
4	Analyze the linkage between economic development and environmental quality from the sustainability framework	New viewpoints to the debate on the relationship between economic development and the environment
5	To measure the contributions of natural capital to countries' productivity and productivity measure	Incorporated natural capital in productivity measures; decomposing natural capital inefficiency score
6	To simulate trajectories of future wellbeing	Measuring long-term sustainability using inclusive wealth framework and shared socio-economic pathways

This thesis is divided into 5 chapters. Chapter 1 presents inclusive wealth framework, objectives, and contributions of the study for the sustainability-related field. Chapter 2 explains the methodology and datasets utilized in this thesis. It includes *IW* framework, Autoregressive Distributed Lag (ARDL), Pooled Mean Group Estimator (PMG), Generalized additive model (GAM), Log Mean Divisia Index (LMDI), Malmquist Productivity Index (MPI), and Weighted Russel Directional Distance Model (WRDDM). Focusing on Indonesia, chapter 3 explores the nexus between sustainability and economic growth in the country, coal consumption and socioeconomics cointegration, and investigate the underlying determinant of emissions change alongside efforts to promote a cleaner cooking fuel program in the country. Utilizing global datasets, 140 countries, chapter 4 analyze the linkage between economic development and environmental quality, capturing the efficient utilization of natural capital to a productivity and efficiency measure, and measuring long-term sustainability. Finally,

chapter 5 describes the thesis conclusions and implications. Moreover, further elaborations of inclusive wealth framework are also suggested. The framework of this thesis is provided in Figure 1.2.
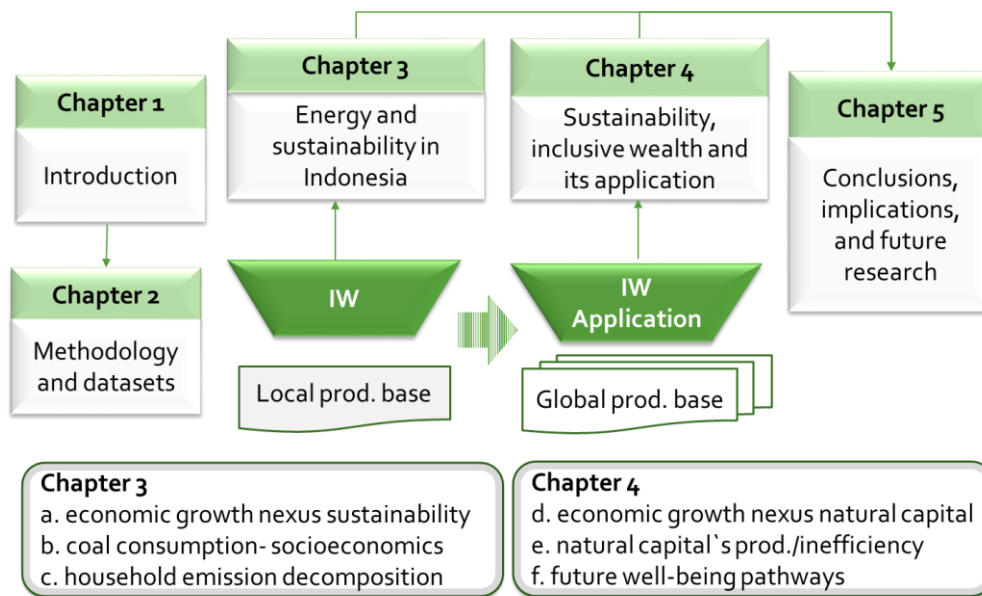

Figure 1. 2 Framework of the thesis

2. Methodology and datasets

This thesis employs several quantitative approaches including the application of inclusive wealth and the statistical methods, such as ARDL, GAM, LMDI, MPI, and WRDDM. In summary, the methods of this thesis are presented in table 2.1.

Table 2. 2 Methodology summary

No	Objectives	Methodology	Study Period
Sustainability and energy in Indonesia			
1	Assessing economic growth from a sustainability perspective	Inclusive wealth framework	1990-2014
2	Discovering the linkage between coal consumption and socioeconomic variables	ARDL	1970-2015
3	Investigate the underlying determinant of emissions change alongside efforts to promote a cleaner cooking fuel program	LMDI	2000-2015
Sustainability, inclusive wealth and its application (140 countries)			
4	Analyze the linkage between economic development and environmental quality from the sustainability framework	*IW* and PMG	1990-2014
5	To measure the contributions of natural capital to countries' productivity and productivity measure	*IW* and WRDDM	1990-2014
6	To simulate trajectories of future wellbeing	*IW* and GAM	1990-2100

2.1 Sustainability and energy in Indonesia

Inclusive wealth accounting

Measured by inclusive wealth per capita, development can be considered sustainable if intergenerational wellbeing does not dwindle over time. It is stipulated as follows:

EQUATION 1

$$V_t = \int_t^\infty U(C_\tau)e^{-\delta(\tau-t)}d\tau$$

In equation 1, V_t refers to wellbeing at time t, U stands for current wellbeing, C_τ covers both market/non-market consumption, and δ represents the social discount rate.

Cointegration analysis

The study employs the ARDL bounds testing approach to examine the cointegration existence among the variables in the presence of structural breaks is calculated using the following equation:

$$lnCo_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} lnCo_{t-1} + \sum_{i=1}^{p} \beta_{2i} lnY_{t-1} + \sum_{i=1}^{p} \beta_{3i}(lnY_{t-1})^2$$
$$+ \sum_{i=1}^{p} \beta_{4i} lnIn_{t-1} + \sum_{i=1}^{p} \beta_{5i} \Delta lnUr_{t-1} + \sum_{i=1}^{p} \beta_{6i} lnTo_{it-1} + \varepsilon_{it}$$

Accordingly, coal consumption per capita (Co_t) are explained by GDP per capita (Y_t), share of secondary industry (In_t), trade openness(TO_t), and urban population (Ur_t).

Emission decomposition

The aggregate household CO_2 emissions can be decomposed into five factors as follows:

$$CO_2{}^t = \sum_{j}^{n} CO_2{}^t_j = \sum_{j}^{n} \frac{CO_2{}^t_j}{EN_j^t} \frac{EN_j^t}{EN^t} \frac{EN^t}{GDP^t} \frac{GDP^t}{POP^t} POP^t$$

$CO_2{}^t$ refers to Indonesia's aggregate CO_2 emissions from the household sector, which captures the CO_2 emissions from both direct CO_2 emissions from household fuel use of type *j*. It represents both direct emissions (kerosene, LPG, and gas) and indirect CO_2 emissions arising from electricity production. Then, I define the following variable of year *t*: EN_j^t, the household energy consumption for fuel type *j*; EN^t, aggregate energy consumption in household sector; GDP^t, Gross Domestic Product; and POP^t for the Indonesian population during the year.

2.2 Sustainability, inclusive wealth and its application

Cointegration analysis for panel data

To understand the relationship between income and natural capital, the study performed the PMG developed by Pesaran et al. (1999) as follows:

$$\ln NC_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \ln NC_{t-i} + \sum_{i=0}^{q} \beta_{2i} \ln GDP_{t-i} + \sum_{i=0}^{r} \beta_{3i} (\ln GDP_{t-1})^2 +$$
$$\sum_{i=0}^{s} \beta_{4i} (\ln GDP_{t-1})^3 + \sum_{i=0}^{t} \beta_{5i} \ln POPDENS_{t-i} + \varepsilon_{it}$$

where NC is the natural capital estimation; GDP is the per capita gross domestic product (GDP), and ε_{it} is the standard error term. To avoid omitted variable bias, the model also include population density (POPDENS) as an independent variable.

Productivity and efficiency measure

This resrach used a deterministic non-parametric analysis based on the data envelopment analysis, a Malmquist productivity index to measure the contribution of the natural capital to countries' productivities. To conduct technical inefficiency decomposition, we employed a new methodological approach proposed by Chen *et al.* (2015) and Barros *et al.* (2012), who used the WRDDM, as defined by the following model:

EQUATION 5

$$\vec{D}\left(x^{k`}, y^{k`}, b^{k`}; g\right) = \rho^{k`} = max w_y \left(\sum_{m=1}^{M} \omega_m^y \alpha_m^{k`}\right) + w_b \left(\sum_{j=1}^{J} \omega_j^b \beta_j^{k`}\right) + w_x \left(\sum_{n=1}^{N} \omega_n^x \gamma_j^{k`}\right) s.t$$

$$\sum_{k=1}^{K} z_k y_{mk} \geq y_{mk`} + \alpha_m^{k`} g_{ym}, m = 1, \dots, M, \sum_{k=1}^{K} z_k b_{jk} = b_{jk`} - \beta_j^{k`} g_{bj},$$

$$j = 1, \dots, J \sum_{k=1}^{K} z_k x_{nk} \leq x_{nk`} - \gamma_n^{k`} g_{xn}, n = 1, \dots, N, z_k \geq 0, k = 1, \dots, K$$

where $\rho^{k`}$ stands for technical inefficiency that measures the maximum expansion of desirable outputs and contraction of undesirable outputs and inputs that remain technically feasible. If $\rho^{k`} = 0$, the DMU $k`$ works on the frontier of $T$ with technical efficiency, meaning that this DMU is fully efficient. Otherwise, $\rho^{k`} > 0$, then DMU $k`$ operates inside the frontier of $T$. The $\alpha_m^{k`}$ refers to the individual inefficiency score of the desirable output y_m, $\beta_j^{k`}$ represents the individual inefficiency score of undesirable output $b_j$, and $\gamma_n^{k`}$ refers to the individual inefficiency score of input x_n. $\omega_x, \omega_y, \omega_b$ represent that the priorities given to the inputs, and desirable and undesirable outputs are normalized to unity.

Future wellbeing prediction

Utilizing the datasets, I developed a statistical model for inclusive wealth using generalized additive models (Hastie and Tibshirani, 1990). Then, I develop forecasts of inclusive wealth using the estimated coefficients from the previous model by considering each country's trajectories under different scenarios for income, population and education.

There are five different Shared Socioeconomic Pathways (SSPs), and during the first part of the study, they are differentiated by their challenges regarding the mitigation of and adaptation to climate change (O'Neill et al., 2014; van Vuuren et al., 2017).

Using generalized additive models, this most general model is:

EQUATION 6

$$log(IW\_percapita_{it}) = \alpha_1 + \eta_i + \gamma_t + f(Log\_GDP\_percapita_{it}) + f(Log\_Population_{it}) + f(Log\_Education\_attainment_{it}) + \varepsilon_{it}$$

Where $IW\_percapita_{it}$ measures inclusive wealth per capita; $GDP\_percapita_{it}$ is per capita gross domestic product PPP (based on US$ 2005). η_i is a country fixed effect, γ_t is a year fixed effect and ε_{it} is a stationary ergodic error term. $f(\cdot)$ is a generic flexible functional form allowing for a potentially non-linear non-monotonic inclusive wealth per capita, GDP per capita, population, and education relationship.

The datasets used in this thesis are provided in table 2.2.

Table 2. 3 Datasets

Variables	Data source
Compensation of employees	(World-Bank, 2016)
	(OECD, 2016)
	(Feenstra et al., 2015)
	(Lenzen et al., 2013)
	(Conference-Board, 2016)
Human capital discount rate	Assumed rate of 8.5%
Education attainment	(Barro and Lee, 2013; Samir and Lutz, 2017)
Employment, labor forces (by age, gender, time)	(ILO, 2016)
Mortality rates by age, gender, time	(WHO, 2016)
Population by ages, gender, time	(UNPD, 2015)
Depreciation rate for produced capital	(Feenstra et al., 2015)
Investment and output for produced capital	(UN-SD, 2016)
Agricultural and pasture land discount rate	Assumed rate of 5%
Harvested area in croplands, permanent crops (agriculture and pastures), price and quantity of crops	(FAO, 2015)
Agricultural and pasture land rental rate	(Aguiar et al., 2012)
Forest stock, area, commercial, wood production, and value	(FAO, 2015)
Forestry rental rate	(Bolt et al., 2002)
Forest ecosystem service	(Van der Ploeg et al., 2010)
Forest area including mangroves, excluding cultivated forest	(FAO, 2015)
Catch of each country's economic exclusive zone for fishery	(Pauly and Zeller, 2016)
Fossil fuel reserves and production	(EIA, 2015)
Fossil fuel prices	(BP, 2015)
Fossil fuel rental rate	(Aguiar et al., 2012)
Minerals reserves, production, prices	(USGS, 2015)
Minerals rental rate	(Aguiar et al., 2012)
Share of secondary industry	(World-Bank, 2017)
Trade openness	(World-Bank, 2017)
Urban population	(UNPD, 2017)
Household energy consumption	(MEMR, 2017)
Households CO_2 emissions	(MEMR, 2017)

Note: Data sources are provided annually, except those for education attainment, forest volume, area, and density. A particular data is reported every five years; we carried linear interpolations to obtain information on an annual basis.

3. Energy and sustainability in Indonesia

3.1 Economic growth and sustainable development in Indonesia

This study applies the inclusive wealth theory, which assesses the productive base wealth types that contribute to wellbeing, including produced capital, human capital, and natural capital. By employing the inclusive wealth framework, I evaluate the extent to which Indonesia achieved economic growth from 1990 to 2014 at the expense of massive natural capital use in violation of basic sustainability criteria. Regarding natural capital, this study consider Indonesian biodiversity by including the ecosystem service valuation for forests, such as mangroves, and for non-timber resources, such as fishery resources and subsoil minerals. This study also consider Indonesia's natural capital account, which consists of forest resources, agricultural land, fossil fuels, and minerals.

Indonesia experienced a GDP growth per capita of 124% between 1990 and 2014, while the inclusive wealth per capita growth was negative (–0.05%). The population grew rapidly during the study period, outpacing total wealth growth, so that per capita wealth growth was considered negative. This study is implied that GDP per capita growth in Indonesia during the period did not necessarily indicate growth in wealth per capita. With a negative inclusive wealth per capita growth, Indonesia was considered to be extracting natural capital more than investing in infrastructure and human capital. The main cause of declining wealth per capita, followed by population growth, is the depreciation of the natural capital. I find Indonesia experienced decreases in both renewable and non-renewable natural capital over the study period. From this standpoint, Indonesia has been extracting natural resources at the expense of the ecological wellbeing of future generations.

Recently, stakeholders have begun to understand that non-renewable resources can, and should, serve as a driver for economic growth and poverty reduction (Aubynn, 2009). In the context of sustainability, however, economic development should be accompanied by environmental stewardship and social progress so that it can be maintained for future generations. As Arrow et al. (2012) suggest, countries on unsustainable trajectories can essentially either increase investments to post-positive gains in the rate of wealth growth, or reduce consumption to levels that their productive base can maintain. Jarvis et al. (2011) discusses several points of policy to support the shift. These include policies to

promote efficient resource extraction, a system of taxes and royalties that allow the government to recover equitable and proportionate shares of rent, and a clear policy for investment in other productive assets.

3.2 Coal consumption, urbanization, and trade openness linkage

Applying the endogenous structural break, it is found that first break in 1981 is statistically insignificant, while the second break in 1997 is statistically significant. The second break which capturing the Indonesian economic crisis followed by cancellation of a significant numbers of coal power plant take into effect the reduction of coal consumption during the period. The coefficients of $\ln Y$ and $\Delta(\ln Y)$ are positive, implying that both in the long run and in the short run, economic development leads to coal consumption in Indonesia. Inverted U-shaped which suggests EKC shape existence between income and coal consumption proven by the negative and significant coefficient of $\ln Y^2$.

The impact of urbanization on coal consumption on lung run is positive and significant at 1% level of significance, implies urbanization increase coal consumption in Indonesia. Even though Indonesia's populations have passed the 50 % urban landmark, according to Jones (2016), potential growth of urban populations through migration still very high in the future. LnIn has negative and significant, it implies decreasing the share of secondary industry value added to total value added in Indonesia. The ratio of the secondary industry value added to GDP capture the composition effect of the economic structure. The industry is associated with more energy consumption, however, in Indonesia, there is decreasing share pattern of secondary industry value added to total value added. Trade openness has positive and significant, which implies that trade increase coal consumption in Indonesia. This finding is consistent with Tiwari et al. (2013) that concluded positive relationship between trade openness with environmental deterioration.

3.3 Cleaner energy conversion and household emission decomposition analysis

This study intends to examine the characteristics of the Indonesian energy matrix and its evolution in the household sector alongside the impact of kerosene to the LPG conversion program to Indonesian emission change in the sector. This study also aim to

investigate the underlying determinant of emissions change, both the direct and indirect effect, from household energy consumption in Indonesia during 2000-2015. To achieve this objective, we conduct the *LMDI* decomposition analysis.

I compare the direct emissions from fuel combustion (kerosene, LPG, and gas) and the indirect emissions from the electricity consumed by the household sector. From direct emission activity, switching kerosene consumption to LPG program would reduce CO_2 emissions by 29% or 8.52 million tons of CO_2 from 2000 to 2015. However, from indirect activity, by including electricity consumption in the household sector, CO_2 emissions increased by 86% or 45.2 million tons of CO_2 during the study period.

When comparing 2015 to 2000, the population, income, and carbon intensity effect led to an increase in both direct and indirect energy emissions, while energy intensity reduced them. The fuel mix effect, which reflects the conversion of kerosene to LPG, has contributed to reduction for direct emission change. However, the high share growth of coal in electricity generation led to increasing indirect emissions for the period.

Dividing the study into three stages, I found the role of national kerosene in the LPG conversion program. The program played a role in reducing emissions in the household sector through carbon intensity improvement, but the effect is limited. During the 2010-2015 period, both direct and indirect emissions from carbon intensity are found to be positive. The fuel mix effect captures the extent to which changes in household emissions are caused by changes in the share of energy consumption by fuel type. Changes in the fuel mix arose from a shift towards kerosene to LPG in final energy use, especially related to cooking activity. Over the kerosene-LPG conversion period, the contribution from the energy mix effect was significant. Energy intensity effect is considered the primary driving factor responsible for slowing down household CO_2 emissions. This effect can offset the positive effects arising from emission from the other factors. It is also noticeable that this factor has increased during the 2010-2015 period.

4. Sustainability, inclusive wealth and its application

4.1 Economic growth – environmental quality nexus

The study main objective is to investigate the existence of EKC hypothesis in a wider picture using natural capital of inclusive wealth. Doing so, I applied the PMG bounds testing approach for panel datasets on 140 countries during the 1990-2014 study period.

From the results of the models, I found no evidence of the conventional EKC hypothesis for the natural capital. At initial stage economic development, low-income countries depend on the local natural capital. Thus, natural capital extraction increase as countries' economic growth tends to develop. Once turning point is achieved, the trend reversed, it present that the beneficial impacts of economic growth on natural are likely to be achieved in the middle-high level of the economic stage. However, natural capital degradation also increases in latest stages of economic development. I also found that population density places constant pressure on natural capital extraction.

Achieving a sustainable development pathway level with a positive natural capital accumulation is a very difficult task during the first stage and even latest stage of economic development. As suggested by Arrow et al. (2012), nations on unsustainable pathway essentially can either reduce the extraction levels to certain degrees that their productive base can maintain or enhance investments to post-positive gains in the rate of wealth growth.

4.2 Efficiency and productivity of natural capital

This study combined the concept of inclusive wealth, including natural capital, as input in productivity and efficiency measurements. Using the applied developed directional distance function, we analyzed the contribution effect of natural capital to efficiency and productivity change as an important addition to the current research of sustainability.

It is found that the adjustment to the conventional productivity growth measure depends on the output growth (GDP) and shift of natural capital relative to other input factors. The adjustment to the conventional TFP growth measure is negative, since natural capital grew faster over the sample period than the traditional input index that combines only human and produced capital input growth. It adjusted to be positively higher for several countries that utilized modest natural capital to accompany their GDP growth.

The adjustment of the conventional and TFP considering natural capital growth measurement may shift over time with respect to resource utilization.

Countries, on average, have high inefficiency scores for natural capital. Natural capital has remained largely hidden to policy-makers due to the limitations of traditional economic indices. It becomes a significant burden to measure most countries' performance, particularly for countries that are oil producers or with depleting forests. As a result, these countries have failed to adequately invest in rebuilding this capital, despite evidence that returns on investment in natural capital far outweigh investment in physical capital, such as infrastructure. Investments in natural capital, particularly agricultural land and forest, can produce several dividends: increasing inclusive wealth and productivity, improving agricultural resiliency and food security, and mitigating climate change, according to UNU-IHDP and UNEP (2014).

4.3 Measuring long-term sustainability

Current and long-term inclusive wealth projections (up to 2100) are crucial to understand global sustainability trajectories. By expanding prior datasets, this study considers the entire production base, which includes the human, natural, and produced capital of 140 countries, as a source of wellbeing. I develop a statistical model for the historical effects of key socioeconomic variables (GDP per capita, population, and education) on country-specific inclusive wealth during the study period. This study offers five newly-developed shared socio-economic pathways, which represent a set of widely diverging narratives. Then, we conduct projections for 2014–2100 along with the five SSPs that strive to explain the implications of key socioeconomic variables on long-term global sustainability. Considering the high level of uncertainty, such scenarios would need to extend a wide range of possible sustainability trajectories.

It is discovered that worldwide inclusive wealth increases with socioeconomic improvement, GDP per capita and educational attainment, while larger populations are related to lower inclusive wealth per capita. Global wealth per capita projections differ widely across the different SSPs. Globally, the range of average inclusive wealth per capita income levels at the end of the century varies. It increases from 2 times 2010 levels for SSP3 to more than 4 times for SSP1. The convergence scenarios, SSP1 and SSP5, and SSP2 as an extension, indicate that medium-high economic growth and educational

attainment outweigh the impact of expected population growth and result in fostering inclusive wealth per capita. However, for SSP3 and SSP4, low-medium economic growth, low investments in education, and medium to high population growth imply lower inclusive wealth per capita trends.

As for convergence patterns, certain countries and regions will catch up with the technological leaders; the share of wealth of Eastern Asia will be more than 25% of total global wealth in 2040. Over the decades, their growth rates will shrink as their productivity nears the frontier and the structure of the aging population in the region reduces its prospects for growth in wealth. In 2100, based on SSP1, SSP5 and to a certain extent, SSP2, South Central Asia will have a share of wealth of more than 20% of total global wealth. Because of their lower education levels and younger population, this particular region has more room to increase their wealth in the future.

Scenarios for the wealth projection in this study were lower in term of inclusive wealth growth rather than projections of global and regional GDP developed by (Dellink et al., 2015). They found, the range of average per capita income levels at the end of the century varies from a less than 3-fold increase over current levels in SSP3 to more than a 16-fold increase in SSP5. In our study, projections of global and regional wealth differ widely across the different SSPs. The range of increasing inclusive wealth per capita is 2 times greater in SSP3 and approximately 4 times greater in SSP1. This difference is related to the different approach of each indicator. GDP represents flow and measure gains in production and output at market prices. Conversely, inclusive wealth captures capital stocks as a source of wellbeing (Dasgupta et al., 2015; Polasky et al., 2015).

5. Conclusions, implications and future research

5.1 Conclusions and implications

To understand the trajectory of sustainability for the local and global scope, there are two main features of this thesis. The first feature discusses energy and sustainability issues within Indonesia scope. The nexus between sustainability and economic growth, the effects of the socioeconomic variables to coal consumption, and the driving forces of emissions were assessed in Indonesia context. Shifting to global analysis, the second feature of this paper discusses three aspects. The linkage between economic development and environmental quality, efficiency and productivity of natural capital, and long-term sustainability measure were explored over global scope. For this purpose, we conducted several quantitative approaches, including the application of inclusive wealth as sustainability measures and combined with the statistical methods.

Utilizing inclusive wealth framework that covers the country's unique resources and biodiversity, it is found that Indonesia's inclusive wealth per capita has been negative within the study period. This study is implied that the GDP per capita growth in Indonesia does not necessarily indicate sustainability. The depreciation of both renewable and non-renewable natural capital is driving the decline in wealth per capita. Despite this, trends show sustainability has been improving, although marginally, due to produced and human capital growth rates. To return to a sustainable growth path, Indonesia must increase its investments to net positive gains at the rate of wealth growth, and it must reduce its resource extraction to levels that its productive base can maintain.

Being part of natural capital, coal is one of the important issue related to sustainability in Indonesia. The effects of economic growth, urbanization, industry, and trade openness on coal consumption in Indonesia over the period 1970–2015 were studied. This study estimates the autoregressive distributed lag method and confirm that the variables are cointegrated for long run linkage with the presence of structural breaks. The empirical evidence showed that economic growth, urbanization and trade openness increase coal consumption while decreasing share of secondary industry reduce it. Having a vital role in the energy mix, Indonesia needs to restrain excessive coal consumption to enhance environmental quality. Having crucial impact to coal consumption, urbanization should be taken into consideration in energy policy-making process.

Another's important issue for sustainable development in Indonesia, the world's fourth most populous country, is their emissions. Using LMDI decomposition analysis, it is found that population and income led to increases of both direct and indirect energy emission, while the impact of energy intensity was the opposite. The fuel mix and carbon intensity effect, which reflects the conversion of kerosene to LPG, contributes to reducing direct emissions with limited effect. High share growth of coal in electricity generation led to increasing indirect emissions for the period. This findings has important policy implications, particularly for increasing the share of new and renewable energy in the national energy mix and for intensifying energy efficiency in the household sector.

Shifting to the global scope, I conducted a study for 140 countries during 1990-2014 periods. This study analyzes the linkage between economic development and environmental quality from the sustainability framework. Conducting a pooled mean group estimator analysis, it is revealed that the beneficial impact of the economy decouples environmental degradation from economic development occurs temporarily. This result shows important implications on natural resources management policy.

Productivity and efficiency measure by using natural capital of inclusive wealth were studied. Applying a weighted Russel directional distance and a Malmquist productivity index, it is found that natural capital remain significant burdens for many countries' performance, especially for countries with resource-driven economies and extreme vulnerability to climatic shifts. The adjustment to a conventional productivity growth measure depends on GDP growth and an endowment growth shift of natural capital relative to other input factors. This finding enhances our understanding of how particular countries can measure and manage their sustainability.

To understand the trajectory of sustainability, it is important to measure historical and future projections of productive capital that contribute to wellbeing. Adapting the inclusive wealth of 140 countries, I develop projections for 2014–2100 using the newly developed shared socio-economic pathways that strive to explain the implications of key socioeconomic variables on long-term global sustainability. Poverty alleviation, demographic changes and human capital investments are effective instruments to attain greater wealth as shown in East and Southeast Asia. Furthermore, the SSP that describes a sustainability pathway is more conducive to increasing wellbeing than the fragmented pathways that result in inequality.

5.2 Future research

This study has several issues that could be addressed in future research. Rely on country scope analysis, it is suggested to assess regional/provincial level to address the highly diverse resources and inequality. Further elaborations, such as greater consideration for the quality of education and health in human capital and socioeconomic inequality, as well as explicitly considering another's ecosystem services in the scenario, would enhance our understanding of future wellbeing. Further elaborations, such as consideration for biodiversity and including more resources such as: livestock, aquaculture, and coral reef also would enrich the sustainability analysis.

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