Global Energy Consumption and Inclusive Wealth

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Global Energy Consumption and Inclusive Wealth

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CERTIFICATE

The undersigned hereby certify that they have read and recommended to the Graduate School of Engineering for the acceptance of this thesis entitled, ‘‘***Global Energy Consumption and Inclusive Wealth***’’ by **Yogi Sugiawan** in partial fulfillment of the requirements for the degree of **Doctor of Engineering**.

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ABSTRACT

Gross domestic product (GDP) and well-being are two different terminologies that cannot be used interchangeably. However, GDP has been inappropriately used as the main indicator for gauging well-being for a long time. As a result, development policies aiming only on sustaining GDP growth tend to deviate from the sustainable development path and eventually fail to maintain the well-being over time. Inclusive wealth (*IW*) offers a new approach to assess the progress toward well-being of a nation by comprehensively measuring the productive base of the economy that involves three types of capital assets of nations (produced, human and natural capital), and aggregates them into a single measure of wealth. The notion of sustainability in the *IW* framework follows the weak perspective. Therefore, a sustainable development path is characterized by a non-declining value of well-being over time while allowing a limited substitutability between each type of capital asset.

However, efforts for pursuing well-being does not necessarily follow a sustainable development path. In most cases, economic development is followed by rapid depletion of natural resources and increasing level of anthropogenic pollution, such as carbon dioxide (CO_2) emissions, which is generally attributed to the increasing level of energy consumption. The strong interrelationship between economic development, energy consumption and CO_2 emissions has led to an ongoing discussion about the sustainability of energy consumption within the policymakers. This paper aims to contribute to the literature by investigating whether the current pattern of energy consumption is associated with the improvement or deterioration of well-being by using the *IW* index as a proxy.

The discussion about the sustainability of energy consumption in this paper is divided into two main parts. The first part contains three

chapters and will discuss about global energy and sustainability issues. In Chapter 2, a novel method for estimating the abundance of global marine fisheries stock is proposed. The topic of this chapter is very intriguing and provide a valuable contribution for the calculation of the natural capital component of the *IW*. Chapter 2 will also discuss the impact of economic growth on marine fisheries stock abundance. Chapter 3 provides a comprehensive analysis of energy-growth nexus in the framework of *IW* for both total and disaggregated wealth. A forecast of the future growth of *IW* in the next three decades is also provided in Chapter 3. Furthermore, a comprehensive analysis of energy and environmental conservation policies issues is provided in Chapter 4. This chapter will assess the impact of CO_2 emission mitigation scenarios on sustainable well-being in the framework of *IW* and provide a projection of CO_2 emission level and wealth for the next 20 years.

Shifting from global analysis, the second part of this paper will focus on a country specific analysis by taking Indonesia as a case study. This paper aims to test the existence of the EKC hypothesis in Indonesia and analyze the impact of renewable energy consumption on shaping the EKC curve. This will be discussed extensively in Chapter 5. Furthermore, the discussion about sustainability of energy should also consider the aspect of social sustainability of the energy technology. Public acceptance is a very crucial aspect that will determine the successful implementation of new energy technologies and its social sustainability. Therefore, this paper attempts to investigate the role of the multilevel managing authorities in shaping public attitudes to nuclear power plants (NPPs) in Indonesia. NPPs were chosen because it is a type of energy technology that always attracts a lot of public controversy. This will be discussed extensively in Chapter 6. Finally, the discussion about the sustainability of energy consumption will be concluded in Chapter 7.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 Introduction

1.1 Income, wealth and well-being

In the light of sustainable development, the vast majority of the existing literature has come to an agreement that well-being is the object that needs to be sustained. Therefore, a sustainable development path is characterized by a non-declining value of well-being over time (see for instance Arrow et al. (2012), Hamilton and Hartwick (2014) and Mumford (2016)). Accordingly, assessment of sustainability of economic development requires quantitative measurement of current and future value of well-being. However, finding a single measure for properly measuring well-being is rather challenging (Mumford, 2016). For more than 70 years, gross domestic product (GDP) has been used as the main indicator for measuring the progress toward the well-being of a nation. However, well-being is a complex multidimensional concept involving not only tangible but also intangible assets, such as human capital, social capital, and environmental services (Costanza et al., 2014; Giannetti et al., 2015; Managi and Kumar, 2018; Mumford, 2016). Hence, despite the outstanding performance of GDP in measuring income and economic activity, it is not a proper tool for gauging well-being. As a result, development policies aiming only on sustaining GDP growth tend to deviate from the sustainable development path and eventually fail to maintain the well-being over time. For instance, Arrow et al. (2012) show that although national economies throughout the globe grow rapidly, their growth is unsustainable since it is followed by the depletion of natural resources and environmental degradation.

Well-being is a yardstick that measures the quality of good life which can be assessed either from objective or subjective point of views (Alatartseva and Barysheva, 2015; Qizilbash, 2009; Veenhoven, 2000; Western and Tomaszewski, 2016). The term well-being that we use in our paper refers to the objective approach which measures the quality of various dimensions of life indicators covering not only material resources, such as income and produced goods, but also social attributes, such as education and health. Numerous alternative indicators beyond GDP for measuring well-being and tracking the sustainability of economic development have been proposed. For instance, Arrow et al. (2012) proposed a comprehensive framework of growth accounting which focuses on wealth, instead of GDP, as a measure of progress toward the well-being of a nation. Wealth can be defined as the sum of capital assets that form the productive base of economy which is measured in physical units and valued in monetary units (Hamilton and Hartwick, 2014). This definition of wealth suggests that unlike GDP, which is a flow variable, wealth is a stock variable which is likely to have a positive correlation with well-being. Therefore, the concept of Inclusive Wealth (*IW*) index was proposed by UNU-IHDP (2012) to comprehensively measure the productive base of the economy covering three types of capital assets of nations which includes produced, human and natural capital. This concept is further expanded by UNU-IHDP (2015) and Managi and Kumar (2018) to include more countries and broader types of natural capital. The notion of sustainability in the *IW* framework follows the weak perspective which allows limited substitutability between each type of capital asset as long as the total wealth can be maintained from being declining over time.

1.2 Energy-growth-environment relationship

Pursuit of well-being does not necessarily follow a sustainable development path. In most cases, economic development is followed by rapid depletion of natural resources and increasing level of anthropogenic pollution, such as carbon dioxide (CO_2) emissions, which is generally attributed to the increasing level of energy consumption. Energy, on the one hand, serves as an essential input for economic activity, but on the other hand, extensive use of energy exerts greater pressure on the environment. This has caused a marked shift in global development issues, from limit to growth, which primarily focused on the scarcity of natural resources, to sustainable development issues, which are concerned about the environmental impact of economic development (Ekins, 1993). Additionally, the threats of extreme climatic events to the sustainability of well-being have urged policymakers to take various countermeasures against the increasing level of anthropogenic CO_2 emissions, particularly from energy combustion. However, the strong interrelationship between economic development, energy consumption and CO_2 emissions has led to a quandary over whether to boost economic growth as high as possible by encouraging higher energy consumption, or giving precedence to environmental sustainability by curbing energy consumption which might result in lower economic growth (Antonakakis et al., 2017).

The existing literature on energy-growth-environment relationship evaluates the sustainability of energy consumption by using two main approaches. The first approach aims to investigate whether environmental degradation can be decoupled from economic growth by testing the existence of the environmental Kuznets curve (EKC) hypothesis. The EKC hypothesis is an enticing concept which was first proposed by Grossman and Krueger (1991). The EKC hypothesis posits that the relationship between economic growth and environmental degradation follows an inverted U-shaped curve. Hence, there is a turning point in the economy subsequent to which the increasing trend in environmental degradation will be reversed. The EKC hypothesis offers a rather promising concept for sustainability since it suggests that instead of being harmful to the environment, economic development is favorable for improving environmental indicators that will eventually lead to a sustainable development path. However, some empirical studies (see for instance Bölük and Mert (2015) and Jalil and Mahmud (2009)) show that the estimated turning point of the EKC might exist at very high levels of income per capita, which are difficult or even impossible to achieve.

Another worth mentioning caveat of the EKC hypothesis is that over the long term, new pollutants and environmental problems might appear, creating a secondary turning point in the economy so that the declining trend in the income-environmental quality relationship will revert back to its former trend (see for instance De Bruyn et al. (1998)).

The second approach for assessing the sustainability of energy consumption focuses on exploring the possibility to detach economic growth from energy consumption through energy-growth nexus study. The Numerous studies have relied on per capita GDP, as a proxy for growth, to investigate whether energy consumption leads to, is neutral to or is driven by economic development (see for instance Ozturk (2010), Tiba and Omri (2017) and Hajko et al. (2018)). Such empirical literature examines the widely known energy-growth causality relationship hypotheses, i.e., growth, conservation, feedback, and neutrality hypotheses. An energy dependent economy is depicted by either a growth or feedback hypothesis, implying that energy is a stimulus for economic growth. Hence, higher economic growth can be achieved by increasing the level of per capita energy consumption, and vice versa. This type of economy tends to be unsustainable because it is usually characterized by the extensive use of non-renewable energy resources and increasing trend in GHG emissions (Gaspar et al., 2017). On the other hand, a more sustainable economy can be found if either conservation or neutrality hypotheses hold true (Menegaki and Tugcu, 2017). These types of energy-growth relationships suggest that energy and environmental conservation policies, aiming to reduce GHG emissions and high dependency on fossil fuels, might be pursued without adversely affecting the economy.

Despite the remarkable contribution of the existing literature on sustainable development studies, it has some noteworthy limitations. For instance, most of the existing literature attempts to evaluate the sustainability of economic development by using GDP as a proxy for well-being. Such approaches are not reliable and might be misleading, since flow variables such as GDP are only a measure of current, but not intergenerational, well-being (Mumford, 2016). Additionally, most of the existing literature on sustainability suffers from a lack of comprehensive assessment because it is mainly focused only on economic security and ecological integrity, disregarding the aspect of social equity of well-being. Social equity is very essential for ensuring equal access to the productive base of economy (Flint, 2013), not only for the current but also for the future generation (Arrow et al., 2012).

1.3 Contributions to literature

The main objective of this paper, therefore, is to comprehensively assess the impact of energy consumption on well-being by using the *IW* index as a proxy. Specifically, this paper aims to investigate whether the current pattern of energy consumption is associated with the improvement or deterioration of well-being. The main contributions of this paper to the literature are as follows:

- providing a comprehensive analysis of energy-growth nexus in the *IW* framework, covering not only total but also disaggregate wealth in terms of produced, human and natural capital;
- providing a comprehensive assessment on the impact of CO_2 emission mitigation scenarios on sustainable well-being;
- proposing a novel method to estimate the abundance of global marine fisheries stock as an integrated part of the natural capital component of the *IW* index;
- providing a comprehensive study on the existence of EKC hypothesis in developing country by taking Indonesia as a case study.

1.4 Thesis framework

The discussion about the sustainability of energy consumption in this paper is divided into two main parts. The first part contains three chapters and will discuss about global energy and sustainability issues. The discussion on sustainability is started in **Chapter 2** by proposing a novel method for estimating the abundance of global marine fisheries stock. The topic of this chapter is very intriguing and provide a valuable contribution for the calculation of the natural capital component of the *IW*. Additionally, this chapter explores the state of global marine fisheries and empirically analyzes its relationship to economic factors. This chapter applies the pooled mean group estimator method to examine 70 fishing countries for the period of 1961-2010 and uses both the catch data and the estimated size of stock as proxies for marine ecosystems. The results from this chapter confirm that economic growth initially leads to the deterioration of marine ecosystems. However, for a per capita income level of approximately 3,827 USD for the catch model and of 6,066 USD for the biomass model, this chapter found beneficial impacts of economic growth on the sustainability of marine fisheries.

Chapter 3 proposes an alternative to the literature on the conventional energy – growth nexus that widely uses GDP as a proxy of the growth. The main objectives of Chapter 3 are to investigate the impact of energy consumption on wealth in the *IW* framework and forecast the growth of *IW* over the next three decades. For this purpose, this chapter uses both parametric and non-parametric analyses on 104 countries for 1993-2014. The main findings of Chapter 3 shows that there is a negative and significant impact of energy consumption on *IW* growth, suggesting an unsustainable pattern of world energy consumption. Using a machine learning technique, this chapter forecasted that increasing the efficiency of energy consumption leads to a higher growth in average per capita *IW*.

A comprehensive analysis of energy and environmental conservation policies issues is provided in **Chapter 4**. This chapter will assess the impact of CO_2 emission mitigation scenarios on sustainable well-being in the framework of *IW* and provide a projection of CO_2 emission level and wealth for the next 20 years. In the light of CO_2

emission mitigation scenarios, better outcome measure is not the economic development itself as previous studies are based, but it is better gauged by considering harmful effects of CO_2 emissions as loss of future well-being. Chapter 4 uses three different energy pathways to forecast the level of CO_2 emissions in the next two decades and foresee their impacts on sustainable well-being in the *IW* framework. This chapter identifies different patterns of *IW* growth from each scenario which varies across time frame, income groups and types of capital. While efficiency scenario leads to the lowest growth in CO_2 emissions, its beneficial impacts on wealth gain are perceptible only on high income group and diminishing in the long run.

Shifting from global analysis, the second part of this paper will focus on a country specific analysis by taking Indonesia as a case study. There are several compelling reasons why Indonesia was chosen as the object of this study. First, Indonesia is a developing country which is currently striving to boost its economy by increasing its amount of energy consumption, as a result it is now facing an increasing threat from climate change and serious environmental problem. Second, despite its huge potential for renewable energy, the utilization of renewable energy in Indonesia remains far beyond their maximum capacity because of either technical or economic constraints. Finally, Indonesia adopts a multilevel government system which cause the implementation of energy-related policy become more challenging.

In **Chapter 5**, this paper aims to test the existence of the EKC hypothesis in Indonesia and analyze the impact of renewable energy consumption on shaping the EKC curve. Although many studies have focused on the EKC, only a few empirical studies have focused on analyzing the EKC with specific reference to Indonesia, and none of them have examined the potential of renewable energy sources within the EKC framework. This chapter attempts to estimate the EKC in the case of Indonesia for the period of 1971-2010 by considering the role of renewable energy in electricity production, using the autoregressive distributed lag (ARDL) approach to cointegration as the estimation method. The results from this chapter show that there is an inverted U-shaped EKC relationship between economic growth and CO_2 emissions in the long run. The estimated turning point was found to be 7,729 USD per capita, which lies outside of our sample period. This chapter also confirms the beneficial impacts of renewable energy on CO_2 emission reduction both in the short run and in the long run.

Furthermore, the discussion about sustainability of energy should also consider the social sustainability of the energy technology. Public acceptance is a very crucial aspect that will determine the successful implementation of new energy technologies and its social sustainability. Therefore, **Chapter 6** attempts to investigate the role of the multilevel managing authorities in shaping public attitudes to nuclear power plants (NPPs) in Indonesia. NPPs were chosen because it is a type of energy technology that always attracts a lot of public controversy. Problems with public acceptance have made NPP projects in Indonesia experience a number of considerable setbacks. Trust in the managing authorities is one of the key factors that is expected to enhance the acceptance of nuclear energy. However, in a country with a multilevel governance system, such as Indonesia, the concept of trust needs to be specified further. By employing both multinomial logit and path models, this chapter shows that nuclear energy authorities and local governments are the key players that positively influence the acceptance of NPPs. Meanwhile, the role of the central government in promoting the acceptance of NPPs is barely perceptible. This chapter shows important implications for the future development of nuclear energy in Indonesia.

Finally, the discussion about the sustainability of energy consumption will be concluded in **Chapter 7**. The framework of this thesis is provided in Figure 1.1.

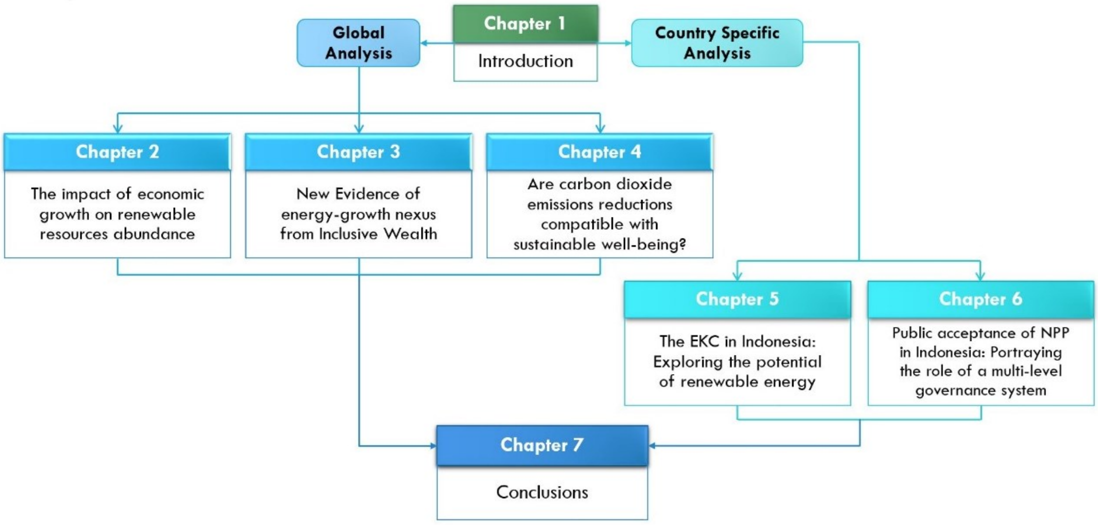

Figure 1.1 Framework of the thesis

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Chapter 2 The impact of economic growth on renewable resources abundance: Case study of global marine fisheries

2.1 Introduction

The ocean provides an enormous amount of resources that are essential not only for providing basic human needs but also for supporting human wealth. However, the ocean's ability to provide sustainable benefits for human well-being is limited by its regenerative capacity, which is currently deteriorating due to overexploitation, pollution and coastal development (Halpern et al., 2012). This has spurred persistent debates regarding the state of global marine fisheries over the last two decades. Several scientists believe that marine fisheries tend to be unsustainable and that the stock of global marine fisheries is facing threats of serial depletion (Hutchings, 2000; Jackson et al., 2001; Pauly et al., 2002; Srinivasan et al., 2010; Worm et al., 2006, 2007; Zeller et al., 2009). This is indicated by the increasing number of fish species that are classified as overfished or as collapsed (Branch et al., 2011; Froese et al., 2012), by declining catch trends (Pontecorvo and Schrank, 2012; Zeller and Pauly, 2005), and by the declining mean trophic levels of catch (Myers and Worm, 2003; Pauly et al., 1998; Pauly and Palomares, 2005). Additionally, Worm et al. (2006) raised concerns even further by arguing that if current trends of fish over-exploitation continue, global marine fisheries are projected to collapse by 2048. On the other hand, arguments against this view contend that current fishing practices are sustainable and that concerns of the collapse of global marine fisheries are slightly exaggerated and misleading (Hilborn, 2007; Murawski et al., 2007; Pauly et al., 2013). Proponents of this view argue that assessments of stock abundance that use catch data as a proxy are not reliable, as a declining catch does not solely denote a declining stock and vice versa. Gephart et al. (2017) show that in addition to cases of fishery collapse, catch levels are also prone to a broad variety of disruptions and shocks such as natural and man-made disasters, policy changes, increasing fuel costs, and low fish prices. Hence, Worm et al. (2006) gloomy projections of the collapse of global marine fisheries, which are based on the assessment of catch time series data, are somewhat misleading (Hilborn, 2007; Murawski et al., 2007).

Regardless of ongoing disputes between these two contradictory views, the amount of fish stock that is being overfished and that has collapsed is rather high. Branch et al. (2011) explain that proportions of fish stocks that are overfished and that have collapsed have been stable in the range of 28–33% and 7–13%, respectively. This denotes an occurrence of resource deterioration due to the exploitation of fish that exceeds maximum sustainable yields and the regenerative capacities of oceans. Economists explain changes in resource availability and environmental degradation based on economic factors. In a simple case, resource degradation is a transient consequence of economic development that is inevitable. However, after reaching a certain level of economic growth, the beneficial impacts of economic growth on resource quality will be achieved, ameliorating damages to nature. If this holds for global marine fisheries, then stock decline can be only temporary and it need not be considered a threat to sustainability over the long term, as further economic growth is expected to lead to stock recovery through the institution of better management systems and policies. This is referred to as the environmental Kuznets curve (EKC) hypothesis. Alternatively, we might find a monotonic relationship or even complex relationship that mainly depends on resource stock estimates and catch data.

Most previous studies due to data availability issues have focused mainly on the impacts of economic growth on pollution levels, which act as an inversely proportional proxy for environmental quality (Grossman and Krueger, 1991; Managi et al., 2009). These studies aim to test the existence of the EKC hypothesis and to find a turning point in the economy after which environmental damages will be ameliorated. However, to the best of our knowledge, only a few studies have examined income-natural resource relationships (see for instance Ewers (2006), Nguyen Van and Azomahou (2007), Caviglia-Harris et al. (2009), and Al-mulali et al. (2015)), and none have examined global marine fisheries within this framework. Our main contributions are at least twofold. First, we attempt to estimate the abundance of marine fisheries by relying on a method proposed by Martell and Froese (2013). Second, we apply an economic model to assess the sustainability of global marine fisheries by examining historical relationships between global marine ecosystems and economic growth. We employ time-series catch and estimated stock data as proxies for measuring the state of the global marine ecosystem.

2.2 Economic development and the state of global marine fisheries

The impacts of economic development on resource abundance can be differentiated into three stages (Grossman and Krueger, 1991). The first stage is referred to as the scale effect, which is characterized by a persistent utilization of heavy machinery, indicating a structural change in an economy. At this stage, economic development has negative impacts on the environment and spurs an upward trend of environmental degradation and resource depletion (Panayotou, 1993). However, as incomes increase, the structure of the economy may change, shifting from a resource-intensive economy to a service- and knowledge-based technology-intensive economy (see Tsurumi and Managi (2010) for more information). This stage is referred to as the composition effect, which is characterized by the development of cleaner industries and by more stringent environmental regulations that limit environmental pressures. Tamaki et al. (2017) show that better resource management practices are beneficial not only for reducing resource exhaustion but also for increasing production efficiency. Finally, a wealthy nation is capable of allocating a higher share of R&D expenditures (Komen et al., 1997), leading to the invention of new technologies that will gradually replace obsolete technologies that tend to be dirtier and less efficient. This stage is referred to as the technical effect, which also contributes to improvements in environmental quality. The cumulative effects of these three different stages of economic development create an inverted U-shaped relationship between economic growth and resource abundance known as the EKC hypothesis.

Although the EKC hypothesis enticingly proposes the existence of a turning point after which further economic growth may lead to environmental improvements, it has some limitations that are worth mentioning. First, the estimated turning point of the EKC can occur amidst very high levels of income. Hence, the beneficial impacts of economic growth on environmental quality are difficult or even impossible to achieve. For instance, Jalil and Mahmud (2009), Bölük and Mert (2015) and Sugiawan and Managi (2016) find a relatively high EKC turning point that lies outside of the observed sample period for the case of carbon dioxide emissions. Second, the EKC hypothesis is not applicable to all environmental/resource problems. For instance, Sinha and Bhattacharya (2017) show a reverse trend of SO_2 emissions, supporting the existence of the EKC hypothesis for 139 cities in India for 2001-2013. However, Nguyen Van and Azomahou (2007) find no evidence of the EKC hypothesis for the case of deforestation in 59 developing countries for 1972-1994. In addition, Liao and Cao (2013) reject the validity of the EKC hypothesis for global carbon dioxide emissions, although they find a flattening trend in carbon dioxide emissions for high-income countries. Another caveat pertains to the fact that the beneficial impacts of economic growth on environmental quality are only temporary. De Bruyn et al. (1998) argue that over the long-term, new technologies will emerge, creating new pollutants and environmental problems. Hence, although the inverted U-shaped relationship is initially observed, a new turning point will appear, leading to a positive correlation between income and environmental degradation. As a result, an N-shaped curve is likely to be observed over the long term. Finally, the composition and technical effects of the economy may also have negative effects on the environment (Tsurumi and Managi, 2010). This might occur as a result of the poor implementation of environmental regulations or due to the invention of more resource-intensive technologies. If this occurs, then an EKC-type relationship is unlikely to be observed.

A scale effect for global marine fisheries was observed in the early nineteenth century, which was marked by the operation of steam trawlers, power winches, and diesel engines (Pauly et al., 2002). This industrialization process has resulted in overfishing and stock collapse (Branch et al., 2011; Froese et al., 2012) and in declining mean catch trophic levels (Myers and Worm, 2003; Pauly et al., 1998; Pauly and Palomares, 2005), suggesting a decline in environmental quality and resource abundance. Figure 4.1 shows the total catch of global marine fisheries obtained through the *Sea Around Us Project* (Pauly and Zeller, 2015). Despite continuous improvements made to fishing methods and technologies, global marine fish catches finally reached a peak in 1996 and declined after experiencing continuous growth for approximately four decades. Fortunately, this decline in the global catch was also followed by a decline in global fishery discards (Zeller and Pauly, 2005), which is attributed to advancements in technology and to the use of more efficient fishing practices.

The composition effect of the economy, which reflects structural changes in the economy, leads to the introduction of new regulatory means of supporting better fisheries management. For instance, the United Nations Convention on the Law of the Sea (UNCLOS), which came into force in 1994, and the individual transferable quota (ITQ) system introduced in the late 1970s act as countermeasures against the collapse of global marine fisheries by boosting the economic benefits of fisheries while maintaining their sustainability (Soliman, 2014). Under the

UNCLOS, the nations of the world are required to maintain rates of marine fishery exploitation at a maximum sustainable yield (MSY). Similarly, the ITQ management system regulates the total allowable catch (TAC) for a particular fish stock and distributes quasi-ownership rights of the TAC to fishermen (Acheson et al., 2015). Despite flaws of the ITQ system (see for instance Acheson et al. (2015)), Costello et al. (2008) show that the ITQ management system helps not only retard the collapse of global marine fisheries but also helps rebuild stock.

2.3 Methodology

2.3.1 Estimating biomass stock

Unlike estimation methods for other renewable natural resources, estimating the abundance of marine fisheries is rather challenging. The most reliable means of determining stock status is the stock assessment technique, which involves conducting scientific surveys to collect data on fish age and size distributions and on catches per unit of effort. However, this method is costly to apply, is time intensive, and requires access to large volumes of data (Agnew et al., 2013). In addition, Kleisner et al. (2013) argue that the technique is only applicable for a small fraction of global stocks, and thus it is not a reliable method for portraying the status of global marine fisheries. They recommend using widely available indicators that can provide a better indication of the status of global marine fisheries, although such indicators may be less precise than those of the stock assessment method. Hence, rather than utilizing stock data drawn from the well-known RAM legacy database (Ricard et al., 2012), we prefer to estimate the stock based on catch time series data drawn through the *Sea Around Us Project* (Pauly and Zeller, 2015), which has broader coverage, accounting for more than 160 countries.

Some previous studies (e.g., Froese and Kesner-Reyes (2002), Pauly et al. (2008), Froese et al. (2012) and Kleisner et al. (2013)) employ the stock status plots (SSP) method, which uses widely available catch data to depict the state of global marine fisheries. However, the SSP method only reveals the qualitative status of fisheries, providing no estimations on the size of fish stocks. To make quantitative estimates of the global marine fish stock, we use a simple yet powerful Schaefer production function (Schaefer, 1954). This model is preferred due to its simplicity and attractive features in terms of determining returns based on fish stocks and effort. Additionally, the model is suited to depicting the state of global marine fisheries, as it uses catch data, which are widely available. The stock of biomass at time t is given by the following equation:

$$B_t = \left(B_{t-1} + r \cdot B_{t-1} \cdot \left(1 - {}^{B_{t-1}}/_{k}\right)\right) - C_{t-1} \qquad (2.1)$$

where B is biomass, C is the annual catch, r is the intrinsic rate of population growth, and k is the parameter of the carrying capacity. While catch C time series data are widely available, other model parameters (r, k, and B) are rather difficult to obtain. However, Martell and Froese (2013) devise a simple means of estimating equation (1) that is strictly based on catch time series data. They propose a means of estimating sets of feasible r and k pairs from a uniform distribution function satisfies the following model assumptions: (1) the estimated biomass is never collapsed, (2) the estimated biomass never exceeds the carrying capacity, and (3) the final stock lies within the assumed range of depletion. The value of r is determined based on the resilience classification of each species, which ranges from 0.05 to 0.5 for low resilience levels, from 0.2 to 1.0 for medium resilience levels and from 0.6 to 1.5 for high resilience levels. Meanwhile, the potential value of k is determined based on the maximum catch volume, which ranges from 1 to 50 times the maximum catch. Additional assumptions on the potential range of the initial and final volume of biomass must also be applied. These assumptions are made based on the ratio between respective catches and the maximum catch (B/k). When the B_0/k ratio is less than 0.5, the initial volume of biomass is assumed to account for approximately 0.5 to 0.9 of the carrying capacity.

Otherwise, it ranges from 0.3 to 0.6 of the carrying capacity. Similarly, the final biomass is assumed to be approximately 0.3 k to 0.7 k when the B/k ratio is greater than 0.5. Otherwise, the value ranges from 0.01 k to 0.4 k. From these pre-determined value ranges, we randomly draw sets of r-k pairs that satisfy the aforementioned model assumptions. Rather than estimating the MSY, our primary interest is to estimate biomass trends. For this purpose, we take the geometric mean of r, k, and the maximum volume of initial biomass, which corresponds to each feasible set of r-k pairs, and include them in equation (1).

From *Sea Around Us Project* catch time series data (Pauly and Zeller, 2015), we estimate the stock of more than 1,400 species in 164 countries for 1950 – 2010 (see Table 2A1 in the appendix for more information). The catch data used in our estimation measure the volume of catches for all purposes in each respective country's exclusive economic zone (EEZ) based on domestic or foreign fleets. Figure 2.1 shows that the global stock has experienced a steady rate of decline along with an increasing catch volume. However, the rate of decline decreased

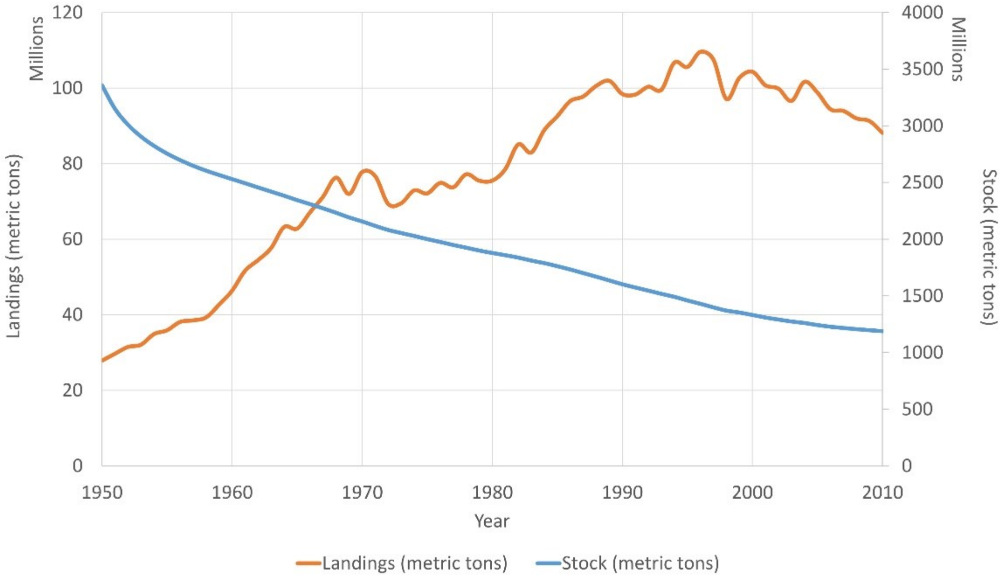

Figure 2.1 Global fisheries catch and estimated stock trends

over the time period, implying beneficial impacts of better fisheries management protocols. We carry out a further analysis of this trend by taking into account different characteristics of each country as is shown in Figure 2.2. We can see that some rich countries that have adopted quota-management systems such as Japan, the UK and the USA have managed to reduce their catch levels and to contribute significantly to declining levels of global catch. As a result, these countries are able to maintain or even recover their stock levels. On the other hand, declining levels of stock are observed for developing countries such as China, Indonesia and Malaysia. These countries are characterized by increasing scales of economy and by relatively high levels of population growth, which are likely to place escalating pressures on marine resources.

2.3.2 Economic modeling

Our paper studies the relationship between economic growth and global marine resources based on the following general parametric models:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln {Y_{it}}^2 + \beta_3 \ln {Y_{it}}^3 + \beta_4 \ln P_{it} + \varepsilon_{it} \qquad (2.2)$$

$$\ln B_t = \gamma_0 + \gamma_1 \ln Y_{it} + \gamma_2 \ln {Y_{it}}^2 + \gamma_3 \ln {Y_{it}}^3 + \gamma_4 \ln P_{it} + \varepsilon_{it} \qquad (2.3)$$

where C is the volume of fish catch; B is the estimated volume of biomass; Y is the per capita gross domestic product (GDP); and ε_{it} is the standard error term. To avoid omitted variable bias, our models also include population density (P) as an independent variable. Halkos et al. (2017) show strong evidence that the decline of natural capital is associated with the increase of another type of capital, such as human capital. Additionally, Merino et al. (2012) show that variations in fish production are also driven by population growth. Furthermore, to account for trends in the variables, we include time trends in our models. We prefer to use the reduced-form model, as it allows us to study the relationship between income and resource abundance both directly and indirectly without being distracted by other variables (see List and Gallet (1999)).

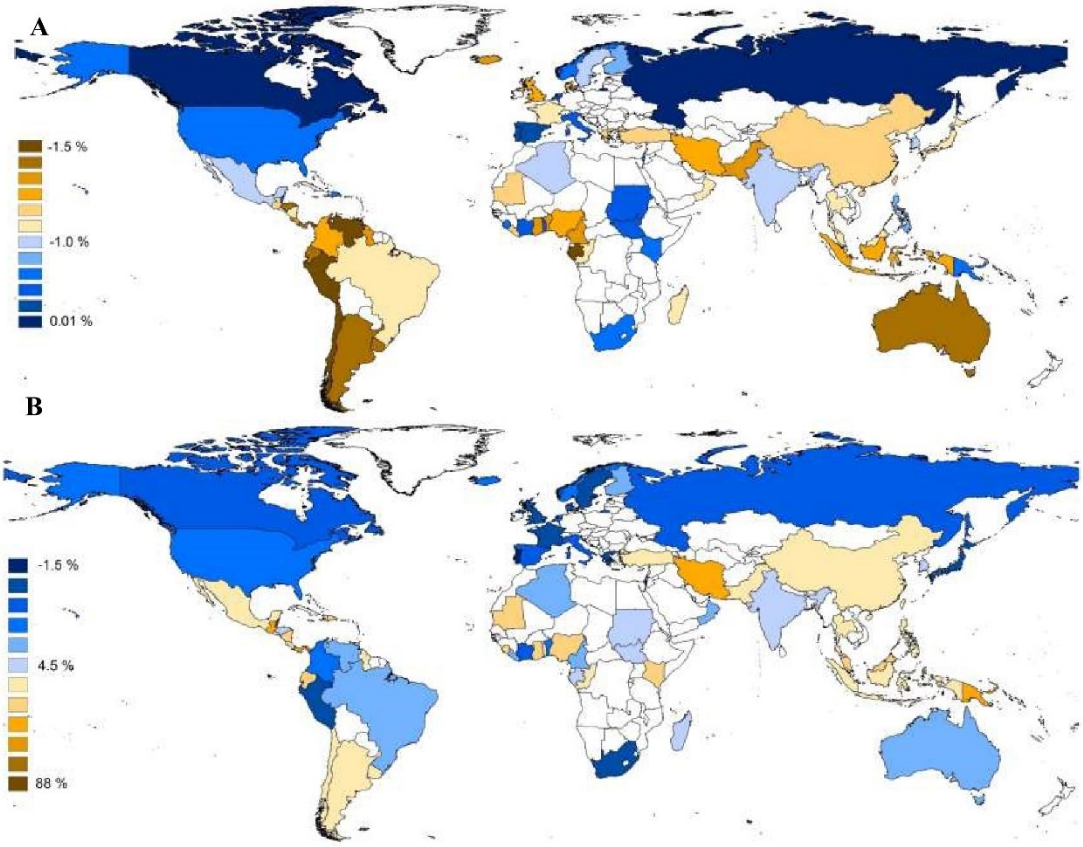

Figure 2.2 Comparison of world catch and estimated stock levels

A. Average annual stock changes from 1961 to 2010 (%). **B**. Average annual catch changes from 1961 to 2010 (%)

Our first model (referred to as the catch model) examines dynamic levels of catch, which act as an inversely proportional proxy for resource abundance, based on variations in economic development. However, a dispute over the reliability of using catch as a proxy for resource abundance might arise, as variations in catch levels are not simply caused by variations in resource abundance. Hence, to ensure the robustness of our findings, we use the estimated size of stock as a proxy for resource abundance in our second model (henceforth referred to as the biomass model). Both of our models provide several possible functional forms of the income-resources relationship[1], i.e., level, linear, quadratic, or cubic, depicting how economic growth will affect resource abundance. A level-type relationship suggests that economic growth is neither harmful nor beneficial for resource abundance. Meanwhile, a linear-type relationship indicates constant pressures of economic growth on resource abundance. The EKC hypothesis is confirmed if there is an inverted U-shaped relationship between per capita income and the volume of catch or a U-shaped relationship between per capita income and the estimated volume of stock, suggesting the existence of a turning point in the economy after which economic growth is beneficial for resource abundance. Moreover, a cubic-type relationship follows either an N- or flipped N-shaped curve, suggesting the existence of a secondary turning point in the economy at which point the trend of the income-resource relationship is reversed a second time.

Our models involve nonstationary heterogeneous panel data of a large number of time-series and cross-sectional observations (50 years of observations for 70 countries). Hence, they cannot be estimated by simply pooling the data and by using fixed or random effect estimators, which assume identical slope coefficients across the groups. Additionally, estimating each group separately via the mean group estimator approach is also inappropriate, as it allows intercepts, slope coefficients, and error variances to differ across groups, overlooking the fact that some parameters may be similar across groups (Pesaran et al., 1999). Therefore, we use the pooled mean group (PMG) method, which combines pooling

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[1] The functional form of the income-resource relationship is determined by the significance of the coefficients β_i and γ_i. A level-type relationship occurs when $\beta_1=\beta_2=\beta_3=0$ or $\gamma_1=\gamma_2=\gamma_3=0$, suggesting that there is no relationship between economic growth and resource abundance. Meanwhile, a linear-type relationship exists when $\beta_2=\beta_3=0$ and $\beta_1\neq0$; or $\gamma_2=\gamma_3=0$ and $\gamma_1\neq0$. Non-linear relationship between economic growth and resource abundance exists when β_2 and/or β_3 or when γ_2 and/or γ_3 are significantly different from zero.

and averaging methods developed by Pesaran et al. (1999). The PMG method allows for heterogeneity in intercepts, short-run coefficients and error variances but restrains long-run coefficients as identical (Pesaran et al., 1999).

The PMG method requires that all variables are not integrated at an order of higher than 1. To obtain the integration properties of our panel data, we use panel unit root tests, which have a higher power compared to individual unit root tests for each cross-section (see for instance Levin et al. (2002)). We employ three panel unit root test methods, e.g., Im, Pesaran and Shin (IPS), Fisher-type Augmented Dickey-Fuller (ADF-Fisher) and Fisher-type Phillips–Perron (PP-Fisher) tests, as suggested by Al-mulali et al. (2015). The aforementioned panel unit root tests have a null hypothesis of non-stationarity and an alternative hypothesis of no panel unit root.

After confirming the stationarity of the variables, the autoregressive distributed lag (ARDL) representation of our models is given by the following equations:

$$\ln C_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \ln C_{t-i} + \sum_{i=0}^{q} \beta_{2i} \ln Y_{t-i} + \sum_{i=0}^{r} \beta_{3i} (\ln Y_{t-1})^2 + \sum_{i=0}^{s} \beta_{4i} (\ln Y_{t-1})^3 + \sum_{i=0}^{t} \beta_{5i} \ln P_{t-i} + \varepsilon_{it} \qquad (2.4)$$

$$\ln B_t = \gamma_0 + \sum_{i=1}^{p} \gamma_{1i} \ln C_{t-i} + \sum_{i=0}^{q} \gamma_{2i} \ln Y_{t-i} + \sum_{i=0}^{r} \gamma_{3i} (\ln Y_{t-1})^2 + \sum_{i=0}^{s} \gamma_{4i} (\ln Y_{t-1})^3 + \sum_{i=0}^{t} \gamma_{5i} \ln P_{t-i} + \varepsilon_{it} \qquad (2.5)$$

and the error correction equations are given by

$$\Delta \ln C_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln C_{t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{r} \beta_{3i} \Delta(\ln Y_{t-1})^2 + \sum_{i=0}^{s} \beta_{4i} \Delta(\ln Y_{t-1})^3 + \sum_{i=0}^{t} \beta_{5i} \Delta \ln P_{t-i} + \pi \; ECT_{t-1} + \varepsilon_t \qquad (2.6)$$

$$\Delta \ln B_t = \beta_0 + \sum_{i=1}^{p} \gamma_{1i} \, \Delta \ln C_{t-i} + \sum_{i=0}^{q} \gamma_{2i} \, \Delta \ln Y_{t-i} + \sum_{i=0}^{r} \gamma_{3i} \, \Delta(\ln Y_{t-1})^2 + \sum_{i=0}^{s} \gamma_{4i} \, \Delta(\ln Y_{t-1})^3 + \sum_{i=0}^{t} \gamma_{5i} \, \Delta \ln P_{t-i} + \pi \, ECT_{t-1} + \varepsilon_t \qquad (2.7)$$

where ECT_{t-1} is the lagged error-correction term and where π is the speed adjustment parameter, which measures the speed of the adjustment of the endogenous variable when there is a shock in the equilibrium. The coefficient of the lagged error correction term is expected to be negative and statistically significant. The optimal lag order is determined based on the smallest Akaike Information Criterion (AIC) and Schwarz's Bayesian Criterion (SBC) values. When the AIC and SBC provide different lag structures, we prefer to use the AIC to prevent our model from being parsimonious.

Data used in our analysis include a balanced panel for 70 countries for 1961-2010. The time span and selection of countries used were constrained by the availability of data. The volume of fish catches (C) and the estimated size of biomass (B) are measured in metric tons. Per capita real GDP (Y) is measured in constant 2005 US dollars. Population density (P) is measured in people per square kilometer of land area. Fish production, per capita real GDP and population density data were obtained from the World Bank World Development Indicators of 2015. The size of biomass was estimated from the *Sea Around Us Project* catch data (Pauly and Zeller, 2015). These data measure the volume of catches for all purposes for each respective country's exclusive economic zone (EEZ) for domestic or foreign fleets. Although our estimation may be less precise than that of the well-known RAM legacy database, it has broader coverage, making it more reliable in terms of reflecting the current state of global marine fisheries.

2.4 The impact of economic growth on catch level and abundance

Our evaluation begins with an examination of integration properties of the variables examined based on three types of panel unit root tests: IPS, ADF-Fisher, and PP-Fisher. The lag lengths of the panel unit root tests are selected based on the SBC value. The test results provided in Table 2.1 show that all of the variables were confirmed as stationary in the first difference.

Table 2.1 Panel unit root tests

Variables	IPS		ADF - Fisher		PP - Fisher	
	Individual Intercept	Individual Intercept and Trend	Individual Intercept	Individual Intercept and Trend	Individual Intercept	Individual Intercept and Trend
Levels						
ln Y	-0.753	0.947	212.021^{***}	132.290	231.278^{***}	90.378
ln P	-0.997	-0.904	206.113^{***}	262.512^{***}	745.435^{***}	201.230^{***}
ln B	11.410	6.587	80.4551	117.079	105.696	30.493
ln C	-1.912^{**}	1.933	200.397^{***}	117.715	284.791^{***}	120.753
First Differences						
ln Y	-32.378^{***}	-31.336^{***}	1222.740^{***}	1077.260^{***}	1284.040^{***}	1209.440^{***}
ln P	-6.008^{***}	-7.221^{***}	321.120^{***}	336.755^{***}	246.980^{***}	210.331^{***}
ln B	-5.580^{***}	-7.540^{***}	301.976^{***}	314.247^{***}	272.804^{***}	279.303^{***}
ln C	-50.008^{***}	-50.467^{***}	1995.330^{***}	1934.220^{***}	2112.530^{***}	3167.560^{***}

Notes: *** , ** and *, denotes statistical significance at 1 percent, 5 percent and 10 percent levels, respectively.

Table 2.2 Model selection summary

Catch Model				Biomass Model			
AIC		SBC		AIC		SBC	
Value	ARDL	Value	ARDL	Value	ARDL	Value	ARDL
-1.203780	2, 1, 1, 1, 1	-0.269545	1, 1, 1, 1, 1	-6.983085	3, 1, 1, 1, 1	-5.916566	2, 1, 1, 1, 1
-1.201876	1, 1, 1, 1, 1	-0.139337	2, 1, 1, 1, 1	-6.982768	4, 1, 1, 1, 1	-5.786531	3, 1, 1, 1, 1
-1.189445	3, 1, 1, 1, 1	0.007109	3, 1, 1, 1, 1	-6.981008	2, 1, 1, 1, 1	-5.654102	4, 1, 1, 1, 1
-1.178145	4, 1, 1, 1, 1	0.150521	4, 1, 1, 1, 1	-6.969135	4, 4, 4, 4, 4	-5.539182	1, 1, 1, 1, 1
-1.148131	2, 2, 2, 2, 2	0.316540	1, 2, 2, 2, 2	-6.964262	4, 3, 3, 3, 3	-5.334852	2, 2, 2, 2, 2

We continue our analysis by determining the optimal lag length to be used in the ARDL model. Table 2.2 presents the top 5 models that minimize the AIC and SBC values by setting the maximum lag order at 4. From Table 2.2, we can see that for both models, the AIC and SBC present different model specifications. We prefer to use the lag structure recommended by the AIC to avoid oversimplifying the model. Thus, we have ARDL (2, 1, 1, 1, 1) for the catch model and ARDL (3, 1, 1, 1, 1) for the biomass model.

Table 2.3 Long- and short-run estimates of the PMG

Variables	**Catch Model:** **ARDL (2,1,1,1,1)**	**Biomass Model:** **ARDL (3,1,1,1,1)**
	Long Run Equation	
$\ln Y$	-12.159620 (2.098682)***	4.427423 (1.070006)***
$\ln Y^2$	1.818432 (0.278766)***	-0.594963 (0.139026)***
$\ln Y^3$	-0.087393 (0.012222)***	0.026085 (0.005974)***
$\ln P$	0.935060 (0.347013)***	-0.354170 (0.102098)***
	Short Run Equation	
$\Delta\ln B_{t-1}$	-	0.591931 (0.029401)***
$\Delta\ln B_{t-2}$	-	0.033832 (0.025134)
$\Delta\ln C_{t-1}$	0.008472 (0.024725)	-
$\Delta\ln Y$	-244.7927 (110.4849)**	9.874210 (9.328565)
$\Delta\ln Y^2$	30.88965 (15.25024)**	-1.116540 (1.124477)
$\Delta\ln Y^3$	-1.337844 (0.737349)*	0.043495 (0.046442)
$\Delta\ln P$	-0.145190 (1.657649)	0.121631 (0.212329)
ECT_{t-1}	-0.238835 (0.017113)***	-0.045471 (0.006564)***
trend	0.002546 (0.001120)**	-0.000561(0.000122)***
cons	8.231275 (0.596153)***	0.241409 (0.035241)***
Number of countries	70	70
Number of obs.	3360	3290
Log likelihood	2604.376	12147.410
SE of regression	0.496437	0.045452

Notes:

1. ***, ** and * denote statistical significance at 1, 5 and 10 percent levels, respectively.
2. The numbers in parentheses are standard errors.

The results of the PMG estimations are provided in Table 2.3. From Table 2.3, we can see that over the long term, the impacts of economic growth on catch and biomass levels are significant. However, the estimated coefficients of the two models have opposite signs, indicating contradictory effects of economic growth on fish production and abundance. The positive and significant coefficient of the cubic term of the catch model suggests that the relationship between income and global levels of catch is best described by a flipped N-shaped curve. Meanwhile, the opposite sign of the cubic term in the biomass model suggests the presence of an N-shaped curve. From Table 2.3, we can also see that population growth is a significant predictor of our models, placing continuous pressure on the environment either by inducing higher catch levels or by deteriorating stock volumes.

The catch model depicts a flipped N-shaped curve with an initial turning point as a local minimum occurring at an income level of 276 USD per capita and with the second turning point as a local maximum occurring at an income level of 3,827 USD per capita. Our findings suggest that in early stages of economic development, higher income levels lead to decreasing catch levels. During this stage, rather than being driven by economic growth, increasing catch levels are mainly caused by population growth. At this stage of economic development, the fisheries sector is dominated by traditional small-scale fisheries. However, after reaching the first turning point, increasing levels of income and population growth lead to higher catch levels, placing more pressure on the environment. This stage of economic development illustrates the scale and technological effects of global marine fisheries, which are marked by the rapid development of industrial-scale fisheries and by advances in technology. This industrialization process has led to the perceptible environmental deterioration of global fisheries (e.g., growing numbers of overfished or collapsed stocks and declining mean trophic catch levels). One the second turning point is reached, the trend reverses. While population growth places continuous pressure on catch levels, further economic growth leads to decreasing catch levels. At this stage of economic development, composition effects of the economy result in the creation of new environmental regulations and cleaner industries that preserve the environment and that undo damages of previous stages of development. However, our catch model does not support the conventional EKC hypothesis, as the flipped N-shaped curve suggests the existence of a secondary turning point beyond which environmental benefits of economic growth will be achieved.

For the biomass model, the first turning point, which is a local maximum, is observed at an income level of 661 USD per capita, and the second turning point, which is a local minimum, is observed at an income level of 6,066 USD per capita. Our model implies that initially, the exploitation of fish will lead to the development of stock, which conforms to Schaefer (1954) production function model. However, beyond the primary turning point, further economic growth leads to stock decline due to the overexploitation of fish above its MSY. This trend reverses again after per capita income levels exceed the secondary turning point, suggesting beneficial impacts of economic growth on resource abundance.

For the short-term, we find significant impacts of economic development on short-run variations at the catch level. However, its impacts on biomass levels are not significant. We also find no significant impacts of population growth on catch and biomass levels for the short-term. Furthermore, the lagged error-correction terms (ECT_{t-1}) for both of our models are negative and statistically significant, confirming the presence of cointegration between variables. These coefficients measure the speed of endogenous variable adjustment when there is a shock in the equilibrium. For the catch model, the absolute value of the lagged error-correction term is 0.238835, indicating a relatively high rate of adjustment in the presence of any shock to the equilibrium. A deviation from equilibrium catch levels in the current period will be corrected with 23.88 percent in the next period. On the other hand, the absolute value of the lagged error-correction term of the biomass model is only 0.045471, which is fairly low. In the presence of any shock to the equilibrium, the volume of biomass will be corrected by only approximately 4 percent in the next period. Our findings imply that while the impacts of scale effects of the economy are perceivable over the short term, beneficial impacts of composition effects of the economy on stock recovery can only be achieved over the long term.

Both of our models suggest that declines in resource abundance are an inevitable consequence of fisheries sector development. However, as the economy grows, the beneficial impacts of economic growth on resource abundance will be attained. This results from the adoption of more stringent environmental regulations, from the implementation of better fisheries management systems and from the use of more advanced technologies. Such processes will spur a decline in catch levels over the short term and stock recovery over the long term. Our findings support Hilborn (2007) argument that declines in abundance should not be considered a serious problem, as they merely serve as a means of achieving sustainable yields.

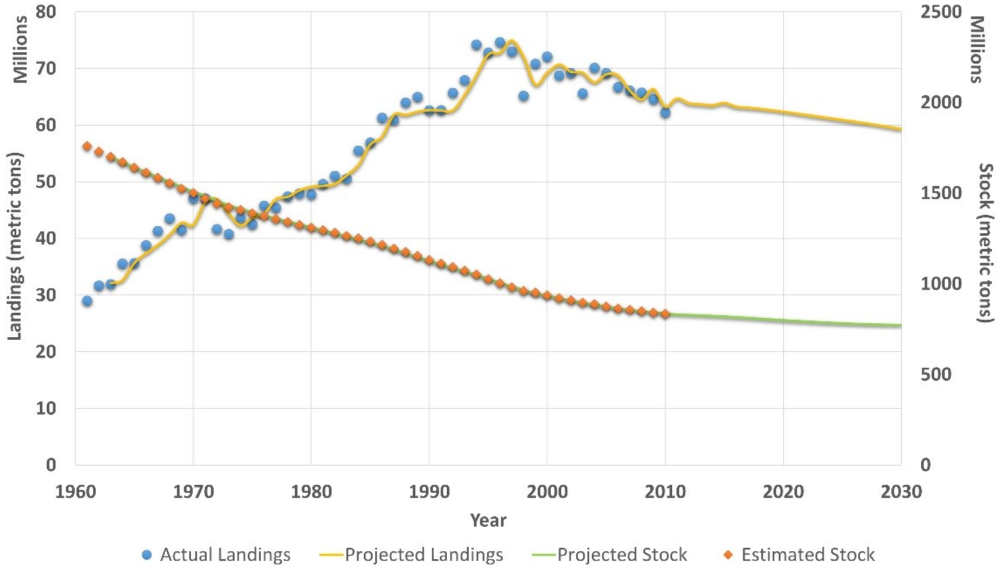

Figure 2.3 Projection of total volume of landing and stock for 70 fishing countries

Based on PMG estimates, we obtain a 20-year forecast from our models. For this purpose, we use the world population prospect of the United Nations to obtain the projected global population of 2030. We also assume that the global economy grows at a constant rate of 2.6 percent per annum. The forecasts of our models are shown in Figure 2.3. From Figure 2.3, we can see that after reaching its peak in 1996, global catch is predicted to decline until 2030. In 2030, the volume of global catch is expected to decrease by 2.8 percent from the 2010 level. Similar trends are observed for the biomass model. However, the trend reverses in 2027. In 2030, we expect to see improvements to global marine fish stocks, although the predicted volume of biomass should still exist below the 2010 level.

A more detailed analysis of the top fishing countries examined (see Figure 2.4) shows that rich countries such as Japan, the UK and the USA contribute positively to declining global catch levels, which in turn prevent the stock from deteriorating further. This highlights the beneficial impacts of better fisheries management systems used in these countries. Interesting findings were found in the case of Malaysia. Unlike those of other middle-income countries, Malaysia's total catch is expected to peak in the near future. However, such declining catch levels are not immediately followed by stock recovery. For other developing countries such as China and Indonesia, we expect to see an increase in catch levels over the next two decades, leading to a steady decline in stock levels.

2.5 Conclusions

The objective of this study was to estimate the state of global marine fisheries and to study its relationship with economic factors. For this purpose, we used both catch levels and the estimated stock of fish as proxies for marine resource abundance. Our models employed panel datasets on 70 fishing countries for 1961-2010.

We found no evidence of the EKC hypothesis for global marine fisheries from catch and biomass stock models. However, our models show that the beneficial impacts of economic growth on global marine fisheries are likely to be achieved. Our catch model reveals the occurrence of a secondary turning point at an income level of 3,827 USD per capita after which further economic growth will lead to a decline in catch levels. In addition, our biomass model presents a secondary turning point occurring at an income level of 6,066 USD per capita after which further economic growth will lead to stock improvements. We also found that population density places constant pressure on resource use by increasing catch levels or reducing stock sizes.

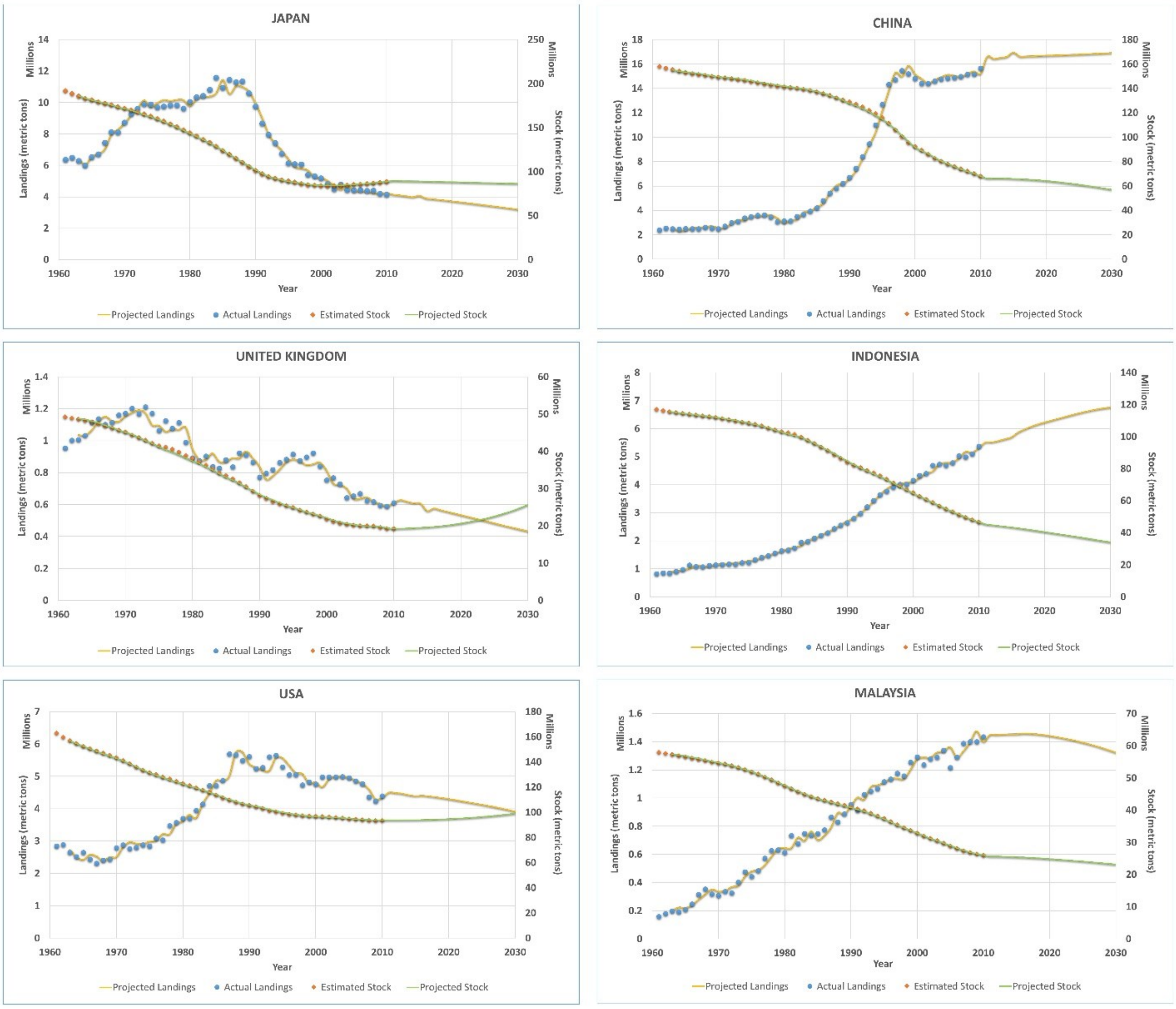

Figure 2.4 Projection of landings and stocks for the examined countries

Our models forecast that over the next two decades, global catch levels should decline alongside economic and population growth. We also expect to find a slight decline in stock levels followed indications of stock recovery. However, our models do not dismiss the need for more stringent environmental regulations and for the use of better fisheries management practices. The higher secondary turning point and the small value of the lagged error-correction term of the biomass model suggest that current quota-based management approaches that attempt to limit the volume of catch might help mitigate pressures on the environment while preventing stock depletion. However, stock recovery is unlikely to be observed over the short term.

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Appendix 2A. Estimated Stock

Table 2A1. Estimated Biomass

No	Country	No. of Species	Year																														
			1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	Albania	9	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11
2	Algeria	185	5.12	4.53	4.18	3.94	3.78	3.66	3.57	3.50	3.44	3.40	3.37	3.33	3.30	3.29	3.28	3.28	3.27	3.27	3.26	3.26	3.25	3.25	3.25	3.24	3.23	3.21	3.19	3.18	3.16	3.15	3.13
3	American Samoa	96	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.06
4	Angola	80	13.18	12.17	11.50	11.06	10.70	10.41	10.11	9.65	9.26	9.04	8.84	8.69	8.54	8.38	8.25	8.00	7.86	7.65	7.47	7.29	6.99	6.77	6.60	6.14	5.82	5.55	5.57	5.66	5.73	5.79	5.86
5	Antigua and Barbuda	32	0.10	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
6	Argentina	61	34.28	32.29	30.93	29.94	29.18	28.58	28.10	27.72	27.40	27.13	26.90	26.70	26.54	26.39	26.23	26.04	25.84	25.61	25.43	25.14	24.95	24.84	24.72	24.60	24.38	24.18	24.13	23.97	23.64	23.07	22.48
7	Aruba	76	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
8	Australia	271	10.82	10.36	10.02	9.75	9.52	9.32	9.17	9.03	8.90	8.79	8.68	8.58	8.49	8.40	8.30	8.22	8.13	8.04	7.96	7.88	7.80	7.70	7.57	7.45	7.33	7.17	7.09	6.98	6.85	6.72	6.59
9	Bahamas, The	45	0.68	0.63	0.60	0.58	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.50	0.49	0.48	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.35
10	Bahrain	36	0.85	0.73	0.67	0.62	0.59	0.57	0.55	0.53	0.52	0.51	0.50	0.49	0.48	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
11	Bangladesh	104	18.34	16.32	15.09	14.24	13.63	13.17	12.81	12.52	12.29	12.10	11.94	11.80	11.67	11.56	11.45	11.36	11.28	11.21	11.14	11.07	11.01	10.95	10.89	10.82	10.76	10.68	10.62	10.56	10.49	10.42	10.35
12	Barbados	44	0.23	0.21	0.20	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10
13	Belgium	75	0.53	0.51	0.49	0.46	0.43	0.40	0.37	0.34	0.34	0.33	0.32	0.32	0.31	0.31	0.31	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.26	0.25	0.25	0.26	0.26
14	Belize	57	0.22	0.21	0.20	0.19	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
15	Benin	89	1.69	1.58	1.51	1.46	1.41	1.38	1.35	1.33	1.31	1.30	1.29	1.27	1.26	1.24	1.23	1.21	1.19	1.16	1.16	1.15	1.13	1.13	1.13	1.12	1.12	1.12	1.12	1.12	1.12	1.11	1.11
16	Bermuda	56	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
17	Bosnia and Herzegovina	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Brazil	260	30.21	28.00	26.61	25.60	24.87	24.27	23.77	23.35	23.01	22.70	22.37	22.04	21.73	21.28	20.84	20.52	20.23	19.90	19.50	19.17	18.89	18.57	18.20	17.74	17.23	16.83	16.49	16.28	15.92	15.47	14.99
19	Brunei Darussalam	54	0.32	0.28	0.26	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
20	Bulgaria	15	0.43	0.41	0.39	0.37	0.36	0.34	0.33	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.24	0.23	0.23	0.22
21	Cabo Verde	39	0.54	0.50	0.47	0.45	0.44	0.42	0.41	0.40	0.39	0.39	0.38	0.38	0.37	0.37	0.36	0.36	0.35	0.34	0.34	0.33	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.30	0.29	0.29	0.29
22	Cambodia	105	31.72	30.13	28.98	28.12	27.44	26.91	26.48	26.13	25.84	25.61	25.41	25.25	25.10	24.98	24.88	24.80	24.68	24.55	24.42	24.25	24.06	23.84	23.61	23.36	23.12	22.91	22.72	22.51	22.15	21.81	21.53
23	Cameroon	60	2.48	2.32	2.21	2.13	2.07	2.02	1.98	1.94	1.90	1.87	1.85	1.83	1.82	1.80	1.78	1.77	1.76	1.75	1.75	1.74	1.73	1.71	1.68	1.65	1.60	1.56	1.52	1.48	1.44	1.40	1.37
24	Canada	172	199.38	192.85	187.49	182.05	177.04	171.55	166.47	161.47	156.70	151.84	146.67	141.14	134.88	129.00	122.72	116.44	109.80	103.67	97.65	91.11	85.79	81.45	77.34	73.62	69.97	67.42	65.50	64.43	65.00	66.36	67.68
25	Cayman Islands	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Chile	86	112.66	109.01	106.46	104.51	102.98	101.75	100.69	99.84	99.13	98.54	98.01	97.37	96.74	96.22	94.76	92.64	92.20	91.05	90.38	89.41	88.89	87.94	87.12	87.12	87.28	86.09	85.36	84.66	83.28	80.93	79.91
27	China	185	219.92	203.34	192.49	184.67	178.89	174.18	170.35	166.92	164.20	161.89	159.88	158.17	156.71	155.36	154.20	153.16	152.19	151.31	150.59	149.84	149.17	148.64	148.06	147.33	146.55	145.65	144.60	143.68	142.72	141.94	141.31
28	Colombia	74	3.23	3.17	3.13	3.09	3.05	3.02	3.00	2.98	2.95	2.92	2.88	2.84	2.78	2.69	2.57	2.52	2.47	2.39	2.29	2.22	2.20	2.13	2.09	2.00	1.84	1.75	1.65	1.65	1.60	1.61	1.63
29	Comoros	21	0.43	0.39	0.37	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
30	Congo, Dem. Rep.	41	0.50	0.46	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.23
31	Congo, Rep.	56	2.02	1.96	1.92	1.88	1.85	1.83	1.80	1.78	1.76	1.73	1.70	1.68	1.66	1.63	1.61	1.57	1.52	1.47	1.46	1.44	1.42	1.40	1.37	1.33	1.29	1.23	1.18	1.12	1.06	1.02	0.97
32	Costa Rica	81	2.68	2.60	2.55	2.50	2.47	2.44	2.42	2.40	2.39	2.37	2.35	2.32	2.29	2.26	2.23	2.18	2.14	2.11	2.08	2.03	2.01	1.98	1.91	1.84	1.74	1.64	1.62	1.60	1.60	1.59	1.57
33	Côte d'Ivoire	139	3.24	3.13	3.05	2.99	2.94	2.89	2.85	2.81	2.77	2.74	2.70	2.66	2.61	2.57	2.52	2.48	2.44	2.39	2.35	2.31	2.28	2.24	2.21	2.19	2.17	2.16	2.15	2.13	2.10	2.07	2.04
34	Croatia	57	1.83	1.72	1.64	1.58	1.52	1.48	1.45	1.41	1.38	1.36	1.34	1.32	1.30	1.29	1.27	1.25	1.24	1.22	1.21	1.19	1.18	1.18	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.08	1.07
35	Cuba	55	1.70	1.64	1.60	1.56	1.53	1.51	1.48	1.46	1.44	1.42	1.40	1.38	1.36	1.34	1.32	1.30	1.27	1.25	1.23	1.21	1.19	1.17	1.14	1.11	1.08	1.04	1.01	0.98	0.95	0.92	0.90
36	Curaçao	28	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04
37	Denmark	135	44.06	42.98	42.06	41.27	40.60	39.82	39.13	38.53	37.91	37.30	36.75	36.26	35.72	35.18	34.58	33.91	33.33	32.81	32.25	31.57	30.95	30.39	29.80	29.27	28.68	28.09	27.34	26.55	25.94	25.33	24.81
38	Djibouti	10	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
39	Dominica	37	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
40	Dominican Republic	92	1.74	1.53	1.40	1.31	1.24	1.19	1.15	1.12	1.09	1.07	1.05	1.03	1.02	1.00	0.99	0.97	0.96	0.95	0.94	0.93	0.92	0.92	0.91	0.89	0.89	0.88	0.87	0.87	0.87	0.87	0.86

No	Country	No. of Species	Year																													
			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	Albania	9	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2	Algeria	185	3.11	3.08	3.04	3.00	2.97	2.92	2.89	2.83	2.76	2.70	2.66	2.64	2.59	2.54	2.45	2.41	2.40	2.38	2.36	2.33	2.28	2.21	2.14	2.06	2.01	1.94	1.84	1.75	1.66	1.59
3	American Samoa	96	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
4	Angola	80	5.97	6.01	6.08	6.16	6.28	6.36	6.45	6.56	6.60	6.63	6.59	6.59	6.60	6.62	6.59	6.57	6.59	6.55	6.48	6.40	6.29	6.19	6.18	6.18	6.20	6.17	6.12	6.05	6.00	5.95
5	Antigua and Barbuda	32	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
6	Argentina	61	22.28	22.15	21.84	21.61	21.55	21.37	21.18	20.89	20.50	20.11	19.65	19.05	18.32	17.38	16.69	15.77	14.81	13.73	12.99	12.39	12.02	11.62	11.24	10.91	10.56	10.26	9.61	8.98	8.16	7.69
7	Aruba	76	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
8	Australia	271	6.50	6.34	6.18	6.02	5.88	5.72	5.58	5.40	5.19	5.00	4.77	4.50	4.32	4.14	4.02	3.88	3.76	3.62	3.49	3.36	3.26	3.14	3.08	2.99	2.91	2.81	2.71	2.70	2.69	2.68
9	Bahamas, The	45	0.34	0.34	0.33	0.32	0.31	0.29	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.26	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21
10	Bahrain	36	0.43	0.42	0.42	0.42	0.41	0.40	0.40	0.39	0.39	0.38	0.38	0.38	0.37	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.29
11	Bangladesh	104	10.28	10.22	10.15	10.08	10.01	9.92	9.82	9.70	9.59	9.48	9.37	9.26	9.14	9.01	8.89	8.76	8.63	8.51	8.39	8.26	8.15	8.02	7.90	7.77	7.57	7.40	7.25	7.11	6.97	6.78
12	Barbados	44	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
13	Belgium	75	0.26	0.25	0.24	0.24	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.28	0.29	0.29	0.30	0.31	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41
14	Belize	57	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
15	Benin	89	1.10	1.10	1.09	1.07	1.06	1.05	1.03	1.01	0.98	0.95	0.91	0.87	0.84	0.81	0.78	0.76	0.73	0.71	0.69	0.67	0.64	0.62	0.59	0.56	0.53	0.49	0.47	0.45	0.44	0.42
16	Bermuda	56	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
17	Bosnia and Herzegovina	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Brazil	260	14.68	14.39	14.05	13.62	13.09	12.58	12.12	11.64	11.30	11.00	10.95	10.86	10.79	10.81	10.79	10.80	10.83	10.77	10.75	10.77	10.75	10.64	10.53	10.49	10.43	10.37	10.29	10.18	10.07	9.93
19	Brunei Darussalam	54	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11
20	Bulgaria	15	0.20	0.19	0.18	0.17	0.17	0.16	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
21	Cabo Verde	39	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.23	0.22	0.21	0.20	0.19	0.18	0.18	0.18	0.17	0.15	0.15	0.14	0.14	0.13
22	Cambodia	105	21.28	20.94	20.51	20.03	19.60	19.10	18.53	17.87	17.36	16.91	16.47	16.07	15.56	15.09	14.57	14.04	13.39	12.73	11.98	11.21	10.44	9.79	9.09	8.39	7.63	6.85	6.17	5.59	5.46	5.31
23	Cameroon	60	1.34	1.32	1.30	1.29	1.27	1.26	1.25	1.24	1.23	1.21	1.18	1.14	1.12	1.09	1.06	1.02	0.99	0.96	0.92	0.88	0.84	0.80	0.77	0.73	0.69	0.67	0.66	0.65	0.65	0.64
24	Canada	172	69.26	70.97	72.82	74.75	76.77	78.59	80.16	81.82	83.50	85.18	86.88	89.04	91.60	94.38	96.93	100.31	103.59	106.80	110.12	113.41	116.63	119.76	122.81	125.75	128.59	131.45	134.25	137.01	139.74	142.11
25	Cayman Islands	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Chile	86	78.70	77.07	73.64	71.36	69.20	66.89	63.84	61.12	58.71	55.30	52.26	49.08	46.32	44.71	42.03	39.36	36.73	35.20	35.10	33.81	33.19	32.53	31.83	31.02	28.84	27.35	26.15	25.43	24.89	24.13
27	China	185	140.78	140.23	139.26	138.35	137.13	135.65	134.28	132.43	130.44	128.96	127.01	124.95	122.07	119.55	115.98	111.59	106.18	100.62	95.56	92.32	89.54	86.09	82.85	80.32	78.06	76.03	74.21	72.28	70.17	68.05
28	Colombia	74	1.63	1.61	1.59	1.60	1.57	1.48	1.46	1.44	1.40	1.37	1.32	1.25	1.12	1.09	1.09	1.08	1.05	1.03	1.01	1.03	1.02	1.02	1.03	1.03	1.05	1.07	1.09	1.08	1.09	1.10
29	Comoros	21	0.28	0.28	0.28	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.21	0.20	0.19	0.18	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.13	0.12	0.12
30	Congo, Dem. Rep.	41	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21
31	Congo, Rep.	56	0.91	0.86	0.82	0.77	0.74	0.72	0.71	0.69	0.69	0.68	0.68	0.69	0.70	0.71	0.71	0.72	0.73	0.74	0.75	0.76	0.76	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.76	0.76
32	Costa Rica	81	1.55	1.51	1.48	1.48	1.44	1.34	1.23	1.17	1.13	1.09	1.07	1.07	1.07	1.05	1.02	1.00	0.97	0.96	0.95	0.94	0.92	0.92	0.88	0.84	0.82	0.80	0.78	0.78	0.79	0.79
33	Côte d'Ivoire	139	2.03	2.02	2.01	2.00	2.00	1.99	1.98	1.96	1.96	1.94	1.92	1.90	1.86	1.82	1.80	1.78	1.76	1.73	1.72	1.69	1.67	1.66	1.65	1.65	1.65	1.65	1.67	1.68	1.69	1.70
34	Croatia	57	1.05	1.03	1.00	0.97	0.94	0.91	0.88	0.84	0.81	0.79	0.77	0.77	0.76	0.74	0.74	0.74	0.75	0.76	0.76	0.78	0.79	0.80	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.79
35	Cuba	55	0.87	0.85	0.83	0.80	0.77	0.74	0.71	0.68	0.66	0.63	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.53	0.52	0.51	0.49	0.49	0.49	0.49	0.49	0.50	0.51	0.51	0.52	0.53
36	Curaçao	28	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
37	Denmark	135	24.16	23.51	22.91	22.39	21.81	21.31	20.71	20.37	19.66	19.02	18.71	18.19	17.47	17.12	16.50	15.77	15.44	15.00	14.70	14.48	14.19	13.80	13.39	13.39	13.32	13.35	13.47	13.75	14.00	14.16
38	Djibouti	10	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
39	Dominica	37	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
40	Dominican Republic	92	0.85	0.84	0.82	0.80	0.78	0.77	0.75	0.73	0.71	0.70	0.68	0.68	0.65	0.63	0.62	0.61	0.61	0.60	0.61	0.60	0.60	0.59	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.57

No	Country	No. of Species	Year																														
			1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
41	Ecuador	69	20.00	19.49	19.16	18.93	18.75	18.61	18.50	18.40	18.32	18.26	18.19	18.14	18.09	18.04	17.96	17.91	17.86	17.81	17.76	17.69	17.62	17.54	17.44	17.31	17.11	16.89	16.62	16.14	15.36	14.25	13.23
42	Egypt, Arab Rep.	73	2.84	2.62	2.48	2.37	2.30	2.23	2.19	2.14	2.10	2.05	2.00	1.96	1.92	1.88	1.83	1.78	1.75	1.74	1.73	1.72	1.72	1.72	1.71	1.70	1.71	1.70	1.69	1.68	1.66	1.65	1.62
43	El Salvador	62	2.31	2.27	2.24	2.22	2.20	2.18	2.17	2.16	2.13	2.10	2.07	1.98	1.88	1.80	1.73	1.65	1.58	1.50	1.45	1.38	1.34	1.30	1.25	1.22	1.15	1.10	1.07	1.04	1.04	0.98	0.95
44	Equatorial Guinea	80	1.34	1.28	1.24	1.21	1.19	1.17	1.15	1.14	1.12	1.11	1.10	1.09	1.08	1.08	1.07	1.06	1.05	1.05	1.04	1.02	1.00	0.99	0.97	0.94	0.92	0.88	0.84	0.79	0.76	0.74	0.74
45	Eritrea	52	0.53	0.50	0.48	0.46	0.44	0.42	0.40	0.38	0.37	0.36	0.36	0.36	0.35	0.34	0.34	0.34	0.32	0.31	0.30	0.29	0.28	0.27	0.25	0.25	0.25	0.25	0.26	0.26	0.27	0.28	0.29
46	Estonia	47	2.57	2.32	2.16	2.04	1.95	1.88	1.82	1.77	1.73	1.70	1.67	1.65	1.63	1.61	1.59	1.57	1.55	1.53	1.52	1.49	1.47	1.45	1.43	1.40	1.38	1.35	1.33	1.31	1.30	1.28	1.27
47	Faroe Islands	90	14.99	14.07	13.37	12.80	12.28	11.75	11.16	10.55	10.31	10.33	10.32	10.40	10.55	10.72	10.86	10.89	10.49	10.14	10.02	9.96	9.97	9.91	9.94	9.99	10.07	10.22	10.32	10.40	10.50	10.53	10.59
48	Fiji	52	1.57	1.52	1.47	1.44	1.41	1.38	1.36	1.33	1.32	1.30	1.28	1.26	1.24	1.23	1.21	1.20	1.18	1.17	1.15	1.14	1.12	1.11	1.10	1.08	1.07	1.06	1.04	1.03	1.02	1.00	0.98
49	Finland	46	3.34	2.94	2.70	2.53	2.40	2.30	2.22	2.16	2.11	2.08	2.04	2.01	1.99	1.97	1.93	1.92	1.90	1.88	1.87	1.84	1.82	1.80	1.78	1.76	1.73	1.71	1.69	1.67	1.64	1.62	1.60
50	France	294	11.35	10.54	9.99	9.60	9.30	9.08	8.89	8.73	8.58	8.44	8.34	8.22	8.08	7.97	7.88	7.80	7.72	7.64	7.54	7.43	7.34	7.28	7.22	7.09	7.03	6.90	6.76	6.56	6.39	6.21	6.06
51	French Polynesia	33	0.64	0.60	0.58	0.56	0.55	0.54	0.53	0.53	0.52	0.51	0.49	0.46	0.43	0.43	0.43	0.43	0.43	0.43	0.42	0.42	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.36	0.35	0.26	0.25
52	Gabon	79	3.58	3.44	3.34	3.26	3.20	3.15	3.11	3.07	3.04	3.02	2.99	2.96	2.94	2.91	2.89	2.86	2.83	2.79	2.74	2.69	2.63	2.60	2.55	2.51	2.46	2.42	2.38	2.32	2.26	2.15	2.05
53	Gambia, The	199	4.88	4.63	4.46	4.34	4.25	4.18	4.12	4.07	4.03	3.99	3.97	3.95	3.93	3.91	3.88	3.86	3.82	3.79	3.76	3.74	3.71	3.62	3.43	3.26	3.16	3.11	3.05	2.99	2.95	2.91	2.88
54	Georgia	37	2.78	2.40	2.20	2.06	1.97	1.91	1.86	1.82	1.79	1.77	1.75	1.73	1.72	1.70	1.69	1.68	1.66	1.65	1.63	1.61	1.59	1.57	1.55	1.52	1.49	1.45	1.41	1.36	1.32	1.26	1.21
55	Germany	118	4.80	4.64	4.51	4.39	4.27	4.16	4.05	3.97	3.88	3.80	3.74	3.70	3.64	3.59	3.51	3.44	3.39	3.31	3.25	3.17	3.12	3.05	3.01	2.96	2.89	2.83	2.78	2.74	2.71	2.71	2.71
56	Ghana	87	13.04	12.29	11.78	11.41	11.11	10.89	10.71	10.54	10.38	10.25	10.13	10.04	9.95	9.86	9.76	9.64	9.53	9.41	9.29	9.20	9.04	8.82	8.57	8.27	8.15	7.99	7.78	7.62	7.43	7.27	7.14
57	Greece	68	5.88	5.46	5.18	4.97	4.81	4.67	4.56	4.47	4.38	4.30	4.23	4.16	4.09	4.04	4.00	3.95	3.92	3.88	3.85	3.82	3.80	3.77	3.75	3.73	3.70	3.67	3.63	3.59	3.55	3.51	3.47
58	Greenland	90	16.17	15.39	14.83	14.30	13.90	13.51	13.15	12.85	12.57	12.21	11.90	11.63	11.32	10.97	10.65	10.34	9.97	9.64	9.32	8.99	8.78	8.66	8.50	8.32	8.20	8.05	7.94	7.85	7.79	7.79	7.75
59	Grenada	50	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05
60	Guam	73	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01
61	Guatemala	84	1.17	1.09	1.04	1.00	0.98	0.95	0.94	0.92	0.91	0.90	0.89	0.88	0.85	0.84	0.83	0.82	0.81	0.80	0.79	0.77	0.77	0.76	0.75	0.74	0.73	0.71	0.69	0.69	0.67	0.66	0.65
62	Guinea	121	11.02	9.69	8.95	8.47	8.12	7.87	7.67	7.51	7.39	7.28	7.19	7.10	7.01	6.91	6.83	6.76	6.71	6.67	6.62	6.57	6.52	6.46	6.40	6.34	6.28	6.21	6.13	6.04	5.93	5.80	5.68
63	Guinea-Bissau	144	8.56	7.93	7.53	7.25	7.05	6.90	6.78	6.68	6.59	6.51	6.44	6.38	6.32	6.26	6.20	6.13	6.08	6.03	5.98	5.92	5.86	5.80	5.74	5.67	5.60	5.52	5.43	5.36	5.24	5.13	5.00
64	Guyana	57	1.43	1.35	1.29	1.24	1.21	1.18	1.16	1.14	1.12	1.11	1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.95	0.94	0.93	0.92	0.91	0.89	0.87	0.86
65	Haiti	67	0.58	0.49	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
66	Honduras	92	0.53	0.51	0.49	0.48	0.47	0.46	0.45	0.45	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.36	0.35	0.35	0.35	0.35	0.34	0.34	0.33	0.32
67	Hong Kong SAR, China	83	0.51	0.50	0.49	0.49	0.48	0.47	0.47	0.46	0.46	0.45	0.45	0.45	0.44	0.44	0.44	0.43	0.42	0.41	0.41	0.39	0.38	0.36	0.35	0.34	0.34	0.33	0.32	0.31	0.30	0.29	0.28
68	Iceland	68	47.30	45.07	43.42	42.16	41.08	40.18	39.40	38.69	38.09	37.56	37.02	36.54	35.97	35.30	34.76	33.97	33.15	32.56	32.28	32.08	31.78	31.48	31.26	31.04	30.71	30.37	30.07	29.75	29.04	28.22	27.38
69	India	206	116.12	102.69	94.67	89.26	85.23	82.10	79.68	77.59	75.79	74.52	73.58	72.54	71.76	71.12	70.62	69.85	69.25	68.63	68.11	67.57	67.15	66.51	65.86	65.39	64.85	64.13	63.30	62.64	62.12	61.48	60.94
70	Indonesia	143	161.01	147.77	139.35	133.49	129.23	126.00	123.52	121.57	120.03	118.79	117.80	117.00	116.25	115.59	115.03	114.52	113.97	113.42	112.98	112.48	111.96	111.25	110.61	109.92	109.19	108.50	107.73	106.74	105.42	104.22	103.15
71	Iran, Islamic Rep.	132	11.25	10.48	9.92	9.48	9.14	8.85	8.62	8.41	8.24	8.08	7.95	7.82	7.71	7.61	7.52	7.43	7.35	7.27	7.19	7.13	7.06	7.01	6.96	6.91	6.87	6.83	6.78	6.72	6.66	6.60	6.55
72	Iraq	12	0.30	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.20	0.19	0.18	0.17	0.17	0.16	0.15
73	Ireland	131	14.23	13.68	13.24	12.88	12.56	12.28	12.07	11.84	11.62	11.41	11.23	11.01	10.90	10.78	10.65	10.53	10.44	10.37	10.28	10.18	10.07	9.94	9.81	9.69	9.57	9.46	9.39	9.36	9.39	9.39	9.38
74	Israel	49	0.16	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
75	Italy	96	24.97	23.90	23.05	22.16	21.50	20.93	20.43	19.95	19.62	19.35	19.13	18.96	18.76	18.66	18.51	18.35	18.17	17.96	17.73	17.56	17.41	17.21	17.05	16.84	16.57	16.28	15.84	15.44	15.11	14.69	14.26
76	Jamaica	62	1.58	1.48	1.41	1.35	1.31	1.27	1.24	1.22	1.19	1.17	1.15	1.14	1.12	1.11	1.09	1.08	1.07	1.05	1.04	1.03	1.02	1.00	0.99	0.98	0.97	0.96	0.94	0.93	0.92	0.91	0.89
77	Japan	159	251.82	239.16	230.31	223.55	217.91	213.23	209.03	205.37	201.65	198.30	195.06	191.98	188.74	185.81	183.20	181.47	179.45	177.72	175.93	173.88	172.16	170.10	167.90	165.63	163.12	160.45	157.53	154.48	151.24	147.64	144.29
78	Jordan	18	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
79	Kenya	45	0.48	0.45	0.42	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.29	0.28	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.23
80	Kiribati	35	4.55	4.17	3.93	3.77	3.65	3.57	3.50	3.44	3.40	3.35	3.30	3.28	3.26	3.23	3.22	3.20	3.19	3.17	3.16	3.15	3.12	3.14	3.15	3.14	3.14	3.14	3.13	3.11	3.09	3.05	3.06

No	Country	No. of Species	Year																													
			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
41	Ecuador	69	12.16	11.41	10.52	10.28	9.24	7.56	6.58	6.05	5.37	4.93	4.90	4.84	4.83	4.68	4.64	4.58	4.23	4.00	4.02	4.05	4.02	3.99	4.11	4.22	4.36	4.44	4.60	4.79	4.92	5.11
42	Egypt, Arab Rep.	73	1.60	1.59	1.58	1.57	1.55	1.53	1.52	1.51	1.48	1.45	1.41	1.38	1.36	1.31	1.29	1.27	1.24	1.21	1.16	1.09	1.06	1.03	1.01	1.00	0.99	0.97	0.95	0.91	0.86	0.83
43	El Salvador	62	0.96	0.93	0.91	0.91	0.85	0.84	0.83	0.82	0.81	0.81	0.82	0.83	0.85	0.85	0.85	0.84	0.82	0.82	0.82	0.84	0.87	0.89	0.91	0.92	0.94	0.95	0.96	0.97	1.00	1.03
44	Equatorial Guinea	80	0.71	0.67	0.64	0.62	0.61	0.59	0.58	0.57	0.56	0.56	0.55	0.55	0.54	0.55	0.54	0.54	0.53	0.53	0.52	0.52	0.52	0.52	0.52	0.53	0.54	0.55	0.55	0.56	0.56	0.57
45	Eritrea	52	0.29	0.30	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.44	0.45
46	Estonia	47	1.26	1.26	1.25	1.24	1.23	1.21	1.20	1.19	1.17	1.16	1.15	1.15	1.15	1.14	1.12	1.09	1.06	1.02	1.00	0.98	0.96	0.94	0.94	0.95	0.95	0.94	0.95	0.95	0.92	0.90
47	Faroe Islands	90	10.73	10.86	11.04	11.15	11.17	11.16	11.08	11.04	11.01	11.01	11.03	11.14	11.23	11.31	11.40	11.32	11.34	11.26	11.16	11.10	10.96	10.68	10.56	10.11	9.85	9.56	9.26	9.08	9.06	9.05
48	Fiji	52	0.97	0.96	0.96	0.95	0.95	0.94	0.94	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.94	0.95	0.95	0.96	0.96	0.95	0.95	0.95	0.96	0.97	0.98	0.98	0.99	0.98
49	Finland	46	1.58	1.58	1.57	1.55	1.53	1.52	1.50	1.49	1.47	1.46	1.45	1.45	1.43	1.41	1.37	1.33	1.30	1.25	1.21	1.17	1.14	1.12	1.12	1.14	1.15	1.14	1.14	1.12	1.10	1.08
50	France	294	5.90	5.85	5.80	5.65	5.55	5.42	5.29	5.20	5.05	4.96	4.88	4.81	4.70	4.63	4.57	4.51	4.49	4.44	4.41	4.33	4.25	4.20	4.14	4.05	3.99	3.93	3.88	3.82	3.81	3.79
51	French Polynesia	33	0.24	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.21	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.27	0.27
52	Gabon	79	1.96	1.87	1.80	1.73	1.69	1.63	1.58	1.55	1.50	1.47	1.44	1.41	1.39	1.37	1.33	1.26	1.23	1.21	1.16	1.12	1.05	1.01	0.96	0.92	0.86	0.82	0.80	0.78	0.75	0.74
53	Gambia, The	199	2.84	2.81	2.78	2.76	2.74	2.65	2.57	2.47	2.36	2.21	1.99	1.79	1.72	1.67	1.64	1.63	1.62	1.62	1.64	1.64	1.64	1.60	1.57	1.52	1.47	1.44	1.41	1.38	1.34	1.31
54	Georgia	37	1.15	1.10	1.05	1.01	0.96	0.92	0.89	0.85	0.81	0.85	0.92	1.00	1.06	1.13	1.20	1.25	1.29	1.32	1.34	1.36	1.37	1.38	1.38	1.37	1.35	1.32	1.29	1.24	1.16	1.10
55	Germany	118	2.71	2.71	2.70	2.69	2.68	2.67	2.68	2.69	2.71	2.73	2.77	2.81	2.84	2.87	2.89	2.91	2.93	2.94	2.97	2.98	3.00	3.01	3.02	3.06	3.08	3.09	3.11	3.13	3.16	3.20
56	Ghana	87	7.03	6.90	6.81	6.73	6.68	6.60	6.50	6.33	6.22	6.12	6.00	5.88	5.71	5.59	5.52	5.41	5.20	5.03	4.87	4.66	4.49	4.34	4.24	4.09	3.92	3.80	3.69	3.62	3.48	3.35
57	Greece	68	3.43	3.38	3.32	3.27	3.20	3.14	3.05	2.97	2.90	2.83	2.77	2.70	2.63	2.55	2.42	2.32	2.23	2.14	2.09	2.04	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.74
58	Greenland	90	7.71	7.77	7.84	7.90	7.97	7.85	7.82	7.80	7.83	7.78	7.75	7.80	7.79	7.73	7.68	7.79	7.91	7.94	7.99	8.03	8.06	8.03	8.00	7.97	7.99	8.02	8.04	8.08	8.12	8.20
59	Grenada	50	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
60	Guam	73	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
61	Guatemala	84	0.64	0.63	0.62	0.62	0.61	0.60	0.60	0.60	0.59	0.58	0.58	0.57	0.56	0.55	0.53	0.51	0.49	0.48	0.46	0.44	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.36	0.36
62	Guinea	121	5.56	5.45	5.35	5.26	5.19	5.15	5.11	5.08	5.05	5.04	4.98	4.89	4.84	4.81	4.81	4.74	4.68	4.55	4.40	4.31	4.17	4.05	3.96	3.92	3.91	3.89	3.81	3.72	3.64	3.51
63	Guinea-Bissau	144	4.78	4.61	4.41	4.23	4.12	3.98	3.79	3.58	3.41	3.18	3.09	3.01	2.99	2.97	2.95	2.92	2.88	2.84	2.81	2.77	2.69	2.63	2.58	2.53	2.49	2.45	2.44	2.43	2.44	2.47
64	Guyana	57	0.85	0.84	0.83	0.82	0.81	0.80	0.79	0.79	0.78	0.77	0.76	0.75	0.75	0.73	0.72	0.70	0.66	0.62	0.59	0.55	0.53	0.50	0.49	0.46	0.44	0.43	0.41	0.40	0.39	0.38
65	Haiti	67	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.19	0.19
66	Honduras	92	0.32	0.31	0.31	0.30	0.30	0.29	0.27	0.26	0.25	0.25	0.25	0.24	0.23	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.17	0.17	0.16	0.15	0.14	0.14	0.14	0.14	0.14	0.14
67	Hong Kong SAR, China	83	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.18	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15	0.16	0.16
68	Iceland	68	26.72	26.18	26.31	26.40	25.78	25.04	24.29	23.58	22.77	22.22	21.68	21.65	21.06	20.39	19.95	19.60	18.85	17.88	17.42	16.98	16.28	15.50	14.61	13.90	13.31	12.81	12.71	12.45	12.28	12.24
69	India	206	60.55	60.08	59.11	58.21	57.52	57.07	56.60	56.16	55.70	54.71	53.61	52.37	51.30	50.71	49.66	48.77	47.54	46.11	44.77	43.68	42.67	42.06	41.18	40.41	39.64	38.98	38.26	37.30	36.40	35.49
70	Indonesia	143	102.42	101.64	99.75	97.73	95.77	93.56	91.30	88.82	86.47	84.15	82.21	80.62	78.95	77.40	75.64	73.51	71.26	69.18	66.99	64.97	62.93	60.92	58.88	56.81	54.84	53.13	51.28	49.55	48.17	46.71
71	Iran, Islamic Rep.	132	6.52	6.48	6.44	6.40	6.36	6.31	6.23	6.13	6.01	5.87	5.74	5.60	5.42	5.27	4.99	4.73	4.49	4.18	3.98	3.75	3.57	3.45	3.34	3.29	3.24	3.20	3.16	3.15	3.11	3.09
72	Iraq	12	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.06
73	Ireland	131	9.32	9.20	9.06	8.92	8.78	8.64	8.50	8.33	8.16	7.94	7.78	7.75	7.71	7.61	7.44	7.11	6.83	6.67	6.31	6.09	5.90	5.82	5.71	5.48	5.25	4.92	4.61	4.37	4.19	4.14
74	Israel	49	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
75	Italy	96	13.91	13.53	13.12	12.82	12.50	12.16	11.86	11.67	11.57	11.52	11.54	11.52	11.52	11.49	11.47	11.42	11.41	11.40	11.36	11.39	11.43	11.55	11.73	11.88	12.06	12.29	12.48	12.70	12.97	13.23
76	Jamaica	62	0.88	0.88	0.87	0.86	0.85	0.85	0.84	0.84	0.85	0.85	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00	1.01
77	Japan	159	140.76	136.91	133.04	128.85	123.99	119.63	114.99	110.44	105.76	101.40	97.48	94.59	92.59	90.67	89.23	88.12	86.40	85.15	84.73	84.06	83.74	83.97	84.51	84.81	85.25	85.72	86.25	86.95	87.62	88.65
78	Jordan	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
79	Kenya	45	0.22	0.21	0.21	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19
80	Kiribati	35	3.04	3.04	3.03	2.99	2.99	2.99	2.98	2.95	2.95	2.95	2.86	2.78	2.67	2.57	2.50	2.56	2.56	2.42	2.26	2.20	2.14	1.99	1.72	1.76	1.78	1.72	1.68	1.65	1.60	1.42

No	Country	No. of Species	Year																														
			1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
81	Korea, Dem. People's Rep.	84	22.84	22.17	21.60	21.09	20.65	20.21	19.77	19.33	18.88	18.44	18.01	17.60	17.22	16.88	16.55	16.25	15.97	15.66	15.35	15.04	14.74	14.45	14.15	13.81	13.46	13.06	12.64	12.05	11.52	10.87	10.27
82	Korea, Rep.	182	73.62	68.30	64.87	62.43	60.62	59.24	58.10	57.07	56.15	55.37	54.72	54.20	53.66	53.16	52.72	52.25	51.80	51.40	51.02	50.60	50.17	49.73	49.24	48.57	47.87	47.02	46.24	45.47	44.64	43.79	42.93
83	Kuwait	24	0.77	0.69	0.64	0.60	0.57	0.55	0.53	0.51	0.50	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.36	0.36	0.36	0.37	0.37	0.37	0.38
84	Latvia	48	3.55	3.23	3.01	2.86	2.74	2.65	2.57	2.51	2.45	2.41	2.37	2.34	2.31	2.29	2.26	2.24	2.22	2.19	2.16	2.12	2.09	2.06	2.03	1.99	1.96	1.92	1.89	1.86	1.84	1.82	1.80
85	Lebanon	20	0.24	0.21	0.19	0.18	0.17	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11
86	Liberia	134	1.76	1.58	1.47	1.40	1.35	1.32	1.29	1.26	1.25	1.23	1.21	1.20	1.18	1.17	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.08	1.05	1.03	1.02	1.01	1.01	1.00	0.99	0.97	0.96
87	Libya	91	1.82	1.65	1.55	1.48	1.43	1.40	1.37	1.34	1.32	1.31	1.29	1.28	1.27	1.27	1.26	1.25	1.25	1.25	1.25	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.23	1.23
88	Lithuania	44	0.87	0.83	0.80	0.78	0.76	0.74	0.72	0.71	0.70	0.68	0.67	0.67	0.66	0.65	0.64	0.64	0.63	0.62	0.62	0.61	0.59	0.58	0.57	0.56	0.55	0.53	0.52	0.51	0.50	0.50	0.49
89	Madagascar	51	3.38	2.99	2.76	2.60	2.50	2.42	2.36	2.31	2.27	2.24	2.21	2.19	2.17	2.15	2.14	2.12	2.11	2.10	2.08	2.06	2.04	2.02	2.00	1.98	1.96	1.94	1.93	1.92	1.90	1.88	1.86
90	Malaysia	171	83.64	75.34	70.35	67.00	64.63	62.87	61.54	60.51	59.71	59.05	58.51	58.05	57.66	57.30	56.95	56.56	56.17	55.78	55.38	54.96	54.65	54.30	53.82	53.28	52.64	51.92	51.22	50.32	49.43	48.45	47.53
91	Maldives	61	3.17	2.86	2.67	2.54	2.44	2.37	2.32	2.28	2.24	2.22	2.19	2.18	2.16	2.15	2.14	2.14	2.12	2.11	2.10	2.09	2.08	2.05	2.03	2.01	1.98	1.95	1.93	1.93	1.93	1.94	1.94
92	Malta	101	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
93	Marshall Islands	60	0.81	0.76	0.71	0.69	0.67	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.59	0.58	0.57	0.57	0.56	0.55	0.54	0.54	0.53	0.53	0.53	0.52	0.50	0.49	0.46	0.44	0.42	0.39	0.38
94	Mauritania	185	22.04	20.33	19.26	18.54	18.01	17.62	17.32	17.09	16.90	16.75	16.62	16.52	16.43	16.33	16.25	16.15	16.05	15.98	15.84	15.61	15.38	15.11	14.80	14.53	14.21	13.78	13.41	12.94	12.68	12.71	12.76
95	Mauritius	46	0.46	0.44	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39	0.38	0.38	0.38	0.37	0.37	0.37	0.36	0.36	0.35	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.31	0.30	0.30	0.30
96	Mexico	142	61.21	56.43	53.36	51.20	49.54	48.21	47.11	46.13	45.40	44.54	43.71	42.91	42.15	41.51	40.89	40.50	40.24	39.95	39.49	39.15	38.93	38.51	38.09	37.67	37.29	37.04	36.77	36.73	36.70	36.14	35.36
97	Micronesia, Fed. Sts.	65	5.32	5.02	4.81	4.66	4.53	4.44	4.35	4.29	4.23	4.17	4.11	4.08	4.03	4.00	3.98	3.95	3.93	3.90	3.88	3.86	3.82	3.81	3.81	3.80	3.75	3.73	3.72	3.71	3.68	3.61	3.57
98	Montenegro	55	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
99	Morocco	175	45.88	41.12	38.33	36.41	35.04	34.07	33.34	32.73	32.17	31.70	31.33	31.02	30.76	30.50	30.27	30.05	29.79	29.38	29.00	28.67	28.24	27.78	27.30	26.72	25.97	25.43	24.93	24.51	23.95	23.63	23.46
100	Mozambique	63	4.69	4.28	4.00	3.79	3.64	3.52	3.42	3.33	3.27	3.21	3.16	3.11	3.07	3.03	3.00	2.97	2.94	2.91	2.88	2.85	2.81	2.78	2.74	2.69	2.65	2.59	2.53	2.47	2.42	2.37	2.31
101	Myanmar	92	38.31	34.64	32.35	30.78	29.65	28.80	28.15	27.63	27.21	26.88	26.62	26.41	26.27	26.15	26.06	26.01	25.93	25.88	25.82	25.74	25.65	25.57	25.48	25.40	25.25	25.16	25.04	24.90	24.77	24.67	24.58
102	Namibia	42	61.03	60.63	60.07	59.31	58.54	57.88	57.33	56.84	56.38	55.97	55.48	55.00	54.41	53.71	52.57	50.96	49.04	46.97	44.01	39.91	36.30	34.36	32.30	30.75	28.80	26.89	24.75	23.11	22.27	21.28	20.91
103	Netherlands	146	14.13	13.59	13.11	12.71	12.29	11.95	11.69	11.46	11.19	10.95	10.72	10.51	10.25	10.01	9.71	9.42	9.21	9.01	8.93	8.79	8.62	8.43	8.26	8.11	7.97	7.83	7.72	7.69	7.70	7.74	7.76
104	New Caledonia	39	0.33	0.29	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.15
105	New Zealand	87	25.37	24.48	23.82	23.30	22.88	22.52	22.22	21.95	21.71	21.52	21.32	21.13	20.99	20.88	20.77	20.67	20.55	20.43	20.31	20.15	20.00	19.84	19.63	19.31	18.98	18.57	18.32	17.83	17.11	16.95	16.68
106	Nicaragua	32	1.12	1.06	1.02	0.99	0.95	0.93	0.91	0.89	0.87	0.85	0.84	0.82	0.80	0.78	0.77	0.75	0.74	0.72	0.70	0.67	0.65	0.62	0.60	0.58	0.55	0.54	0.52	0.50	0.48	0.47	0.46
107	Nigeria	49	10.30	9.49	8.97	8.61	8.34	8.14	7.98	7.86	7.76	7.68	7.62	7.56	7.52	7.48	7.45	7.41	7.37	7.34	7.30	7.27	7.25	7.21	7.12	7.04	6.97	6.90	6.85	6.79	6.73	6.69	6.64
108	Northern Mariana Islands	83	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.07	0.07	0.06	0.06	0.05	0.04
109	Norway	136	81.93	75.81	71.72	68.86	67.03	65.07	63.83	62.43	61.40	60.59	59.76	58.98	58.26	57.76	57.29	56.85	56.09	54.44	52.29	51.00	50.13	49.02	48.07	47.06	46.25	45.49	44.95	43.50	41.96	41.24	40.58
110	Oman	59	5.19	4.64	4.30	4.07	3.90	3.76	3.64	3.55	3.47	3.41	3.35	3.31	3.26	3.22	3.18	3.15	3.12	3.08	3.05	3.02	3.00	2.98	2.96	2.94	2.92	2.89	2.87	2.84	2.81	2.78	2.74
111	Pakistan	122	25.03	23.11	21.91	21.08	20.39	19.86	19.42	19.06	18.80	18.56	18.36	18.16	17.99	17.87	17.72	17.52	17.32	17.09	16.90	16.75	16.59	16.43	16.30	16.13	15.94	15.81	15.68	15.53	15.35	15.08	14.86
112	Palau	54	1.36	1.18	1.08	1.01	0.97	0.94	0.91	0.90	0.88	0.87	0.86	0.85	0.84	0.84	0.83	0.83	0.82	0.82	0.81	0.81	0.81	0.80	0.79	0.80	0.79	0.79	0.79	0.79	0.79	0.80	0.80
113	Panama	52	5.19	4.97	4.81	4.69	4.60	4.52	4.45	4.38	4.32	4.27	4.21	4.16	4.12	4.06	3.94	3.84	3.76	3.64	3.57	3.52	3.51	3.49	3.45	3.43	3.38	3.36	3.34	3.24	3.10	3.06	2.99
114	Papua New Guinea	52	6.75	5.71	5.16	4.82	4.59	4.41	4.29	4.19	4.11	4.04	3.98	3.95	3.91	3.86	3.84	3.80	3.79	3.75	3.73	3.71	3.67	3.41	3.17	3.22	3.24	3.20	3.23	3.23	3.25	3.27	3.32
115	Peru	49	292.92	281.47	272.59	265.55	259.88	255.24	251.37	248.05	245.07	242.07	238.14	233.07	226.50	218.51	211.57	202.24	196.09	188.57	179.65	170.63	163.87	152.41	143.93	143.57	146.44	146.82	148.13	148.28	150.83	152.16	153.54
116	Philippines	160	37.09	32.27	29.52	27.72	26.46	25.52	24.80	24.25	23.83	23.47	23.18	22.94	22.73	22.53	22.31	22.07	21.83	21.60	21.38	21.12	20.93	20.76	20.61	20.42	20.21	20.03	19.81	19.61	19.43	19.28	19.15
117	Poland	53	5.07	4.86	4.70	4.56	4.44	4.34	4.25	4.17	4.10	4.04	3.98	3.93	3.89	3.84	3.80	3.77	3.73	3.69	3.65	3.59	3.54	3.48	3.43	3.37	3.31	3.24	3.16	3.10	3.04	3.00	2.95
118	Portugal	239	13.18	12.79	12.45	12.13	11.81	11.51	11.28	11.02	10.77	10.52	10.29	10.05	9.80	9.56	9.30	8.98	8.66	8.43	8.20	8.02	7.92	7.73	7.57	7.41	7.23	7.14	7.08	7.01	6.96	6.93	6.90
119	Puerto Rico	37	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11
120	Qatar	43	0.25	0.24	0.22	0.22	0.21	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17

No	Country	No. of Species	Year																													
			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
81	Korea, Dem. People's Rep.	84	9.72	9.14	8.58	8.22	7.91	7.63	7.32	6.93	6.64	6.33	6.31	6.41	6.52	6.61	6.72	6.87	7.12	7.39	7.69	8.00	8.31	8.63	8.94	9.26	9.49	9.79	10.09	10.41	10.73	11.08
82	Korea, Rep.	182	42.14	41.31	40.63	39.89	39.14	38.51	37.56	36.82	36.17	35.45	34.75	34.22	33.72	32.91	32.17	31.44	31.19	31.26	30.70	29.87	29.23	28.85	28.61	28.40	28.04	27.66	27.26	26.83	26.34	26.10
83	Kuwait	24	0.39	0.39	0.38	0.37	0.36	0.35	0.35	0.33	0.31	0.30	0.30	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.24
84	Latvia	48	1.77	1.74	1.72	1.69	1.66	1.63	1.61	1.59	1.57	1.56	1.55	1.54	1.53	1.53	1.51	1.48	1.42	1.36	1.34	1.33	1.32	1.32	1.31	1.31	1.30	1.30	1.30	1.30	1.29	1.27
85	Lebanon	20	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08
86	Liberia	134	0.95	0.93	0.91	0.90	0.89	0.87	0.85	0.83	0.79	0.77	0.74	0.72	0.71	0.70	0.69	0.68	0.67	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.55	0.54	0.52	0.51
87	Libya	91	1.22	1.22	1.21	1.20	1.19	1.18	1.17	1.16	1.15	1.14	1.13	1.13	1.12	1.11	1.10	1.08	1.07	1.05	1.04	1.01	0.98	0.95	0.91	0.87	0.82	0.78	0.75	0.70	0.66	0.62
88	Lithuania	44	0.48	0.47	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.41	0.40	0.40	0.39	0.38	0.37	0.35	0.32	0.31	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.24	0.24	0.23
89	Madagascar	51	1.84	1.82	1.80	1.78	1.76	1.74	1.71	1.67	1.65	1.63	1.60	1.58	1.55	1.52	1.47	1.44	1.41	1.37	1.33	1.30	1.27	1.24	1.21	1.19	1.17	1.14	1.12	1.09	1.06	1.02
90	Malaysia	171	46.65	45.75	44.97	44.23	43.64	43.07	42.57	41.97	41.52	40.97	40.42	39.82	39.03	38.24	37.41	36.43	35.47	34.59	33.77	32.86	31.98	31.26	30.53	29.72	28.87	28.16	27.46	26.84	26.42	26.01
91	Maldives	61	1.94	1.93	1.93	1.92	1.91	1.88	1.86	1.84	1.82	1.80	1.77	1.73	1.70	1.68	1.72	1.75	1.77	1.79	1.80	1.82	1.83	1.83	1.82	1.81	1.65	1.50	1.35	1.27	1.20	1.12
92	Malta	101	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
93	Marshall Islands	60	0.37	0.36	0.36	0.33	0.34	0.35	0.35	0.35	0.35	0.36	0.37	0.38	0.38	0.38	0.38	0.39	0.39	0.39	0.34	0.33	0.32	0.27	0.23	0.23	0.22	0.21	0.20	0.20	0.20	0.19
94	Mauritania	185	12.59	12.36	12.10	11.87	11.72	11.51	11.26	10.90	10.52	10.17	9.84	9.54	9.42	9.36	9.37	9.42	9.34	9.20	9.05	8.92	8.77	8.56	8.41	8.24	7.98	7.67	7.57	7.41	7.22	7.03
95	Mauritius	46	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.25	0.25	0.23	0.22	0.22	0.20	0.19	0.17	0.16	0.16	0.15	0.15	0.15	0.15	0.14
96	Mexico	142	34.25	32.80	31.80	31.24	30.72	30.12	29.51	28.80	28.23	27.51	26.93	26.28	26.02	25.75	25.40	24.88	24.27	23.67	23.48	23.30	23.06	22.79	22.49	22.16	22.07	22.12	22.09	21.94	21.64	21.41
97	Micronesia, Fed. Sts.	65	3.55	3.49	3.46	3.40	3.25	3.19	3.00	2.88	2.71	2.59	2.50	2.40	2.25	2.10	1.99	1.86	1.81	1.82	1.83	1.76	1.67	1.65	1.65	1.49	1.38	1.22	1.04	0.82	0.84	0.79
98	Montenegro	55	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
99	Morocco	175	23.21	23.02	22.80	22.47	22.25	22.03	21.70	21.47	20.95	20.47	20.04	19.65	19.51	19.28	18.88	18.42	18.30	17.98	17.74	17.56	17.16	16.52	16.16	15.92	15.68	15.45	15.37	15.35	15.16	14.83
100	Mozambique	63	2.24	2.18	2.12	2.07	2.03	1.99	1.94	1.90	1.86	1.82	1.79	1.75	1.72	1.69	1.66	1.64	1.62	1.60	1.58	1.56	1.55	1.54	1.53	1.53	1.53	1.54	1.55	1.56	1.58	1.60
101	Myanmar	92	24.49	24.40	24.26	24.10	23.92	23.73	23.48	23.17	22.88	22.58	22.25	21.90	21.47	20.99	20.40	19.78	19.10	18.50	17.90	17.28	16.59	15.97	15.33	14.71	14.09	13.47	12.92	12.46	12.19	11.91
102	Namibia	42	20.56	19.89	19.39	18.80	18.47	18.28	18.31	17.49	17.25	17.44	17.90	18.56	19.09	19.51	20.08	20.76	21.53	22.33	23.05	23.77	24.50	25.25	25.95	26.61	27.34	28.07	28.84	29.70	30.57	31.40
103	Netherlands	146	7.74	7.69	7.57	7.45	7.34	7.12	6.93	6.78	6.64	6.46	6.35	6.28	6.24	6.18	6.15	6.10	6.16	6.22	6.21	6.20	6.22	6.27	6.34	6.41	6.49	6.60	6.70	6.83	6.97	7.07
104	New Caledonia	39	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
105	New Zealand	87	16.40	16.03	15.68	15.25	14.71	14.31	13.79	12.98	12.13	11.43	10.96	10.56	10.12	9.81	9.51	9.22	8.96	8.63	8.26	7.96	7.73	7.50	7.26	6.98	6.74	6.58	6.40	6.25	6.17	6.11
106	Nicaragua	32	0.45	0.44	0.44	0.45	0.45	0.45	0.46	0.47	0.47	0.48	0.48	0.48	0.48	0.48	0.48	0.47	0.46	0.45	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.36	0.36	0.36	0.37
107	Nigeria	49	6.60	6.54	6.47	6.40	6.31	6.23	6.15	6.06	5.96	5.85	5.79	5.64	5.50	5.36	5.22	5.06	4.91	4.75	4.60	4.45	4.29	4.14	3.99	3.82	3.67	3.51	3.35	3.21	3.06	2.93
108	Northern Mariana Islands	83	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
109	Norway	136	40.04	39.21	38.46	37.43	36.91	36.71	36.88	36.99	37.16	37.42	37.88	37.62	37.26	36.64	36.11	35.47	34.92	34.11	33.67	33.41	33.09	32.84	32.51	32.43	32.50	32.74	33.07	33.17	33.22	33.13
110	Oman	59	2.71	2.69	2.67	2.63	2.60	2.56	2.54	2.49	2.41	2.38	2.33	2.31	2.27	2.20	2.17	2.10	2.06	2.03	2.01	1.99	1.96	1.92	1.88	1.84	1.77	1.72	1.67	1.62	1.57	1.52
111	Pakistan	122	14.66	14.41	14.19	13.94	13.68	13.42	13.17	12.88	12.54	12.24	11.87	11.49	11.12	10.61	10.33	10.06	9.81	9.51	9.24	8.92	8.66	8.38	8.12	7.88	7.58	7.38	7.16	6.96	6.74	6.53
112	Palau	54	0.78	0.76	0.73	0.70	0.67	0.65	0.64	0.62	0.62	0.61	0.63	0.62	0.62	0.63	0.63	0.62	0.58	0.55	0.56	0.55	0.55	0.56	0.55	0.54	0.52	0.51	0.50	0.47	0.43	0.39
113	Panama	52	2.87	2.82	2.75	2.61	2.57	2.38	2.34	2.28	2.28	2.21	2.21	2.18	2.15	2.10	2.06	2.00	1.98	1.94	1.85	1.86	1.75	1.62	1.52	1.45	1.42	1.40	1.40	1.38	1.35	1.30
114	Papua New Guinea	52	3.34	3.34	3.31	3.30	3.27	3.19	3.13	3.07	3.06	2.91	2.79	2.64	2.58	2.56	2.44	2.19	2.17	2.19	2.25	2.33	2.33	2.40	2.49	2.49	2.49	2.49	2.46	2.42	2.37	2.26
115	Peru	49	156.09	158.61	159.75	163.17	164.31	164.41	162.45	162.01	158.28	153.81	150.53	147.02	142.42	135.96	125.07	119.27	112.67	108.42	110.29	105.47	97.30	93.28	87.74	85.90	78.87	72.32	69.13	65.55	61.78	58.47
116	Philippines	160	19.05	18.95	18.84	18.75	18.67	18.61	18.53	18.43	18.35	18.16	17.95	17.74	17.46	17.14	16.84	16.57	16.31	16.07	15.76	15.48	15.21	14.91	14.56	14.21	13.87	13.46	13.20	12.81	12.38	11.96
117	Poland	53	2.88	2.82	2.76	2.69	2.62	2.56	2.51	2.47	2.44	2.41	2.39	2.37	2.34	2.30	2.21	2.12	1.98	1.83	1.73	1.66	1.58	1.51	1.47	1.42	1.37	1.34	1.31	1.26	1.24	1.20
118	Portugal	239	6.81	6.72	6.67	6.64	6.58	6.48	6.36	6.26	6.20	6.15	6.15	6.15	6.14	6.13	6.17	6.21	6.27	6.35	6.43	6.53	6.65	6.75	6.87	6.98	7.10	7.20	7.30	7.39	7.45	7.55
119	Puerto Rico	37	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11
120	Qatar	43	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.12	0.11	0.11	0.10	0.10

No	Country	No. of Species	Year																														
			1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
121	Romania	26	0.34	0.33	0.32	0.31	0.30	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.21
122	Russian Federation	193	250.38	235.10	223.97	215.69	209.18	203.85	199.11	195.06	191.65	189.14	187.19	185.73	184.33	183.17	181.78	180.57	179.20	177.82	176.37	174.59	173.18	171.78	170.38	169.24	166.92	164.67	161.95	159.42	157.01	154.93	153.10
123	Samoa	60	0.42	0.39	0.37	0.36	0.34	0.33	0.33	0.32	0.31	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.23
124	São Tomé and Principe	141	1.07	1.02	0.97	0.94	0.91	0.88	0.86	0.85	0.83	0.82	0.80	0.79	0.78	0.77	0.77	0.76	0.75	0.75	0.73	0.71	0.69	0.68	0.66	0.63	0.62	0.61	0.60	0.58	0.56	0.56	0.55
125	Saudi Arabia	75	2.26	2.15	2.07	2.01	1.97	1.94	1.91	1.88	1.86	1.84	1.82	1.81	1.79	1.77	1.75	1.73	1.71	1.68	1.63	1.59	1.54	1.51	1.48	1.44	1.39	1.37	1.34	1.32	1.28	1.26	1.26
126	Senegal	156	28.12	26.93	26.09	25.46	24.97	24.57	24.21	23.90	23.63	23.38	23.08	22.76	22.47	22.17	21.88	21.58	21.32	21.06	20.76	20.40	19.95	19.46	18.90	18.31	17.76	17.19	16.60	16.08	15.64	15.28	15.00
127	Seychelles	34	1.47	1.36	1.29	1.24	1.20	1.17	1.15	1.13	1.11	1.10	1.09	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.05	1.00	0.99	0.99	0.98	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99
128	Sierra Leone	131	6.31	5.37	4.87	4.54	4.31	4.14	4.01	3.91	3.83	3.76	3.70	3.65	3.58	3.51	3.44	3.39	3.35	3.31	3.27	3.23	3.20	3.17	3.14	3.10	3.05	3.01	2.96	2.92	2.88	2.84	2.82
129	Singapore	61	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16
130	Sint Maarten (Dutch part)	26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
131	Slovenia	68	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
132	Solomon Islands	14	1.87	1.70	1.60	1.53	1.47	1.43	1.41	1.39	1.37	1.36	1.35	1.35	1.34	1.32	1.32	1.32	1.32	1.31	1.31	1.31	1.30	1.30	1.24	1.25	1.26	1.25	1.26	1.25	1.25	1.24	1.24
133	Somalia	96	3.06	2.81	2.66	2.55	2.48	2.42	2.37	2.34	2.31	2.29	2.27	2.26	2.24	2.23	2.23	2.22	2.21	2.20	2.20	2.19	2.18	2.17	2.16	2.16	2.16	2.15	2.15	2.14	2.13	2.13	2.12
134	South Africa	101	39.38	37.93	36.74	35.62	34.70	33.92	33.27	32.76	32.27	31.75	31.20	30.58	29.83	29.06	28.23	27.38	26.48	25.60	24.42	22.79	21.45	20.82	20.24	19.71	18.96	18.17	17.46	16.95	16.66	16.33	16.04
135	Spain	251	29.13	28.06	27.06	26.34	25.69	25.08	24.40	23.85	23.31	22.77	22.24	21.74	21.17	20.71	20.21	19.80	19.39	19.01	18.64	18.26	17.95	17.56	17.34	17.11	16.84	16.63	16.31	16.05	15.75	15.53	15.38
136	Sri Lanka	120	13.52	12.06	11.21	10.63	10.21	9.89	9.64	9.43	9.27	9.12	9.00	8.89	8.79	8.69	8.61	8.51	8.46	8.41	8.36	8.31	8.27	8.23	8.21	8.18	8.15	8.10	8.04	7.98	7.93	7.79	7.67
137	St. Kitts and Nevis	30	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
138	St. Lucia	56	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08
139	St. Martin (French part)	32	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
140	St. Vincent and the Grenad	66	0.20	0.19	0.18	0.18	0.17	0.17	0.16	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08
141	Sudan	23	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
142	Suriname	70	1.86	1.67	1.56	1.48	1.43	1.38	1.35	1.32	1.30	1.28	1.27	1.25	1.23	1.21	1.20	1.18	1.17	1.15	1.14	1.12	1.10	1.07	1.05	1.02	0.99	0.97	0.94	0.93	0.91	0.90	0.89
143	Sweden	85	11.97	11.11	10.49	10.02	9.64	9.34	9.09	8.88	8.69	8.53	8.39	8.27	8.17	8.07	7.97	7.89	7.80	7.71	7.61	7.49	7.39	7.31	7.24	7.16	7.05	6.95	6.85	6.76	6.68	6.61	6.52
144	Syrian Arab Republic	167	13.62	13.15	12.81	12.53	12.30	12.09	11.90	11.72	11.55	11.39	11.23	11.10	10.95	10.80	10.64	10.48	10.33	10.19	10.04	9.88	9.71	9.53	9.36	9.18	8.99	8.84	8.64	8.43	8.15	7.88	7.68
145	Tanzania	91	3.12	2.81	2.62	2.49	2.38	2.31	2.24	2.19	2.15	2.12	2.09	2.06	2.04	2.02	2.00	1.98	1.96	1.93	1.91	1.88	1.87	1.85	1.83	1.80	1.79	1.77	1.72	1.68	1.64	1.60	1.58
146	Thailand	90	70.15	65.01	61.48	58.89	56.89	55.31	54.03	52.96	52.06	51.29	50.62	50.03	49.49	48.97	48.45	47.88	47.11	46.30	45.46	44.53	43.57	42.56	41.52	40.50	39.64	39.15	38.76	38.37	37.50	36.86	36.47
147	Togo	112	1.52	1.43	1.38	1.33	1.30	1.27	1.25	1.22	1.20	1.18	1.16	1.14	1.13	1.11	1.09	1.08	1.06	1.05	1.03	1.02	1.00	0.99	0.97	0.96	0.94	0.92	0.91	0.90	0.89	0.89	0.87
148	Tonga	78	0.21	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12
149	Trinidad and Tobago	95	0.92	0.87	0.84	0.81	0.79	0.77	0.75	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.67	0.66	0.65	0.65	0.64	0.63	0.61	0.60	0.58	0.57	0.56	0.54	0.53	0.52	0.50	0.49	0.47
150	Tunisia	84	2.19	2.01	1.89	1.81	1.75	1.70	1.67	1.64	1.61	1.59	1.58	1.56	1.54	1.53	1.51	1.50	1.49	1.48	1.46	1.45	1.44	1.44	1.43	1.42	1.41	1.40	1.39	1.37	1.35	1.33	1.31
151	Turkey	112	24.20	22.10	20.72	19.75	19.06	18.48	18.05	17.66	17.37	17.14	16.94	16.78	16.66	16.59	16.41	16.28	16.10	15.98	15.72	15.60	15.44	15.28	15.16	15.05	15.00	14.99	14.99	14.95	14.89	14.71	14.37
152	Turks and Caicos Islands	29	0.35	0.33	0.32	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.28
153	Tuvalu	77	0.38	0.35	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.26
154	Ukraine	34	3.32	3.18	3.06	2.97	2.90	2.84	2.80	2.76	2.73	2.70	2.68	2.66	2.64	2.61	2.59	2.56	2.54	2.50	2.48	2.46	2.45	2.43	2.41	2.40	2.38	2.33	2.29	2.20	2.14	2.08	2.00
155	United Arab Emirates	64	2.05	1.93	1.84	1.79	1.74	1.71	1.68	1.65	1.63	1.61	1.60	1.58	1.56	1.55	1.54	1.52	1.51	1.50	1.49	1.48	1.47	1.46	1.45	1.44	1.43	1.41	1.39	1.37	1.35	1.33	1.32
156	United Kingdom	260	60.37	58.10	56.35	54.98	53.77	52.79	51.99	51.32	50.72	50.19	49.72	49.25	48.92	48.61	48.28	47.94	47.39	46.80	46.21	45.68	45.22	44.39	43.73	43.02	42.19	41.55	41.13	40.58	39.84	38.86	38.16
157	United States	557	220.20	208.40	199.93	193.14	187.63	182.83	178.68	174.86	171.74	168.94	165.99	162.98	159.82	156.97	154.72	152.56	150.53	148.78	147.22	145.43	143.54	141.29	138.67	135.91	133.56	131.54	129.92	128.05	126.61	124.78	123.04
158	Uruguay	45	3.64	3.42	3.28	3.18	3.11	3.06	3.01	2.98	2.95	2.92	2.90	2.88	2.86	2.84	2.82	2.80	2.78	2.77	2.74	2.73	2.73	2.73	2.72	2.71	2.71	2.70	2.69	2.66	2.62	2.55	2.46
159	Vanuatu	62	0.23	0.21	0.20	0.19	0.19	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.14	0.14
160	Venezuela, RB	116	10.09	9.66	9.32	9.07	8.85	8.67	8.50	8.35	8.21	8.09	7.98	7.88	7.79	7.71	7.62	7.55	7.46	7.40	7.32	7.23	7.14	7.07	6.97	6.85	6.73	6.65	6.55	6.47	6.40	6.33	6.28
161	Vietnam	121	66.52	59.08	54.67	51.77	49.75	48.18	46.91	45.92	45.12	44.45	43.84	43.18	42.64	42.04	41.40	40.82	40.35	39.95	39.63	39.36	39.14	38.97	38.84	38.74	38.67	38.63	38.64	38.55	38.55	38.58	38.58
162	Virgin Islands (U.S.)	36	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
163	West Bank and Gaza	26	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
164	Yemen, Rep.	63	6.87	6.33	5.99	5.74	5.56	5.43	5.32	5.25	5.19	5.14	5.10	5.07	5.04	5.02	5.00	4.98	4.96	4.95	4.93	4.91	4.90	4.88	4.86	4.84	4.80	4.75	4.71	4.64	4.57	4.52	4.47

No	Country	No. of Species	Year																													
			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
121	Romania	26	0.21	0.20	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.13
122	Russian Federation	193	151.20	148.98	146.11	143.20	138.68	133.97	129.18	125.21	121.68	117.38	112.72	108.24	104.33	102.19	101.28	98.89	95.11	91.50	88.96	87.30	86.73	86.10	87.09	87.44	89.09	90.25	91.36	91.93	92.51	92.58
123	Samoa	60	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.18	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15
124	São Tomé and Principe	141	0.55	0.54	0.53	0.52	0.51	0.50	0.48	0.46	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.36	0.35	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.32
125	Saudi Arabia	75	1.26	1.25	1.23	1.21	1.18	1.14	1.06	1.03	1.00	0.97	0.95	0.93	0.90	0.88	0.82	0.80	0.77	0.74	0.71	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.68	0.68	0.67
126	Senegal	156	14.63	14.37	14.12	13.93	13.73	13.54	13.35	13.01	12.75	12.51	12.14	11.82	11.40	11.10	10.87	10.70	10.34	10.06	9.83	9.63	9.50	9.35	9.25	9.20	9.11	9.00	8.95	8.96	9.02	9.08
127	Seychelles	34	1.00	1.00	1.00	1.00	0.97	0.95	0.93	0.91	0.86	0.82	0.81	0.79	0.75	0.71	0.70	0.65	0.65	0.64	0.65	0.65	0.65	0.62	0.60	0.53	0.47	0.43	0.39	0.35	0.33	0.32
128	Sierra Leone	131	2.79	2.77	2.75	2.73	2.72	2.71	2.70	2.68	2.66	2.64	2.61	2.61	2.61	2.62	2.63	2.64	2.66	2.69	2.72	2.74	2.73	2.68	2.61	2.51	2.42	2.34	2.26	2.19	2.12	2.04
129	Singapore	61	0.16	0.16	0.15	0.14	0.13	0.13	0.12	0.12	0.13	0.13	0.13	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09
130	Sint Maarten (Dutch part)	26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
131	Slovenia	68	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
132	Solomon Islands	14	1.24	1.24	1.24	1.23	1.19	1.20	1.21	1.23	1.23	1.22	1.21	1.20	1.20	1.19	1.19	1.19	1.18	1.17	1.12	1.13	1.17	1.17	1.19	1.17	1.09	1.00	0.92	0.85	0.74	0.72
133	Somalia	96	2.11	2.10	2.09	2.08	2.06	2.04	2.03	2.00	1.98	1.97	1.94	1.92	1.88	1.84	1.79	1.75	1.67	1.61	1.56	1.49	1.43	1.38	1.31	1.16	1.04	0.92	0.87	0.84	0.82	0.79
134	South Africa	101	15.92	15.80	15.75	15.58	15.64	15.66	15.65	14.99	14.47	14.39	14.68	15.02	15.14	15.40	15.70	15.96	16.36	16.69	16.97	17.23	17.42	17.49	17.55	17.55	17.48	17.48	17.69	17.84	18.01	18.30
135	Spain	251	15.27	15.16	15.05	15.07	15.04	15.09	15.19	15.29	15.41	15.52	15.64	15.73	15.84	15.95	16.00	16.06	16.16	16.23	16.32	16.43	16.59	16.70	16.94	17.18	17.46	17.67	17.84	18.10	18.36	18.61
136	Sri Lanka	120	7.53	7.43	7.34	7.27	7.22	7.20	7.16	7.13	7.07	7.04	7.02	6.99	6.89	6.78	6.66	6.49	6.31	6.19	6.07	5.94	5.74	5.52	5.28	4.97	4.73	4.73	4.56	4.44	4.32	4.21
137	St. Kitts and Nevis	30	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
138	St. Lucia	56	0.08	0.08	0.07	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07
139	St. Martin (French part)	32	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
140	St. Vincent and the Grenad	66	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11
141	Sudan	23	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
142	Suriname	70	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86	0.86	0.86	0.87	0.87	0.86	0.86	0.85	0.83	0.82	0.81	0.79	0.78	0.76	0.74	0.72	0.70	0.67	0.66	0.65	0.62	0.60	0.60
143	Sweden	85	6.40	6.29	6.18	6.06	5.91	5.80	5.72	5.66	5.58	5.50	5.44	5.39	5.31	5.20	5.03	4.85	4.68	4.51	4.32	4.21	4.13	4.09	4.07	4.09	4.09	4.09	4.11	4.14	4.18	4.20
144	Syrian Arab Republic	167	7.47	7.29	7.08	6.89	6.70	6.47	6.24	6.05	5.87	5.65	5.48	5.36	5.26	5.20	5.14	5.04	4.93	4.85	4.81	4.79	4.80	4.81	4.78	4.70	4.63	4.54	4.51	4.54	4.59	4.62
145	Tanzania	91	1.56	1.53	1.53	1.52	1.49	1.47	1.45	1.43	1.41	1.39	1.36	1.34	1.31	1.31	1.30	1.30	1.26	1.25	1.23	1.20	1.18	1.15	1.12	1.10	1.07	1.04	1.03	1.01	0.99	0.97
146	Thailand	90	36.27	36.03	35.70	35.38	35.27	35.17	34.80	34.20	33.78	33.34	32.86	32.23	31.35	30.43	29.43	28.38	27.61	27.13	26.67	26.23	25.66	25.34	25.13	24.82	24.63	24.33	23.90	23.96	23.72	23.55
147	Togo	112	0.86	0.84	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.74	0.74	0.75	0.76	0.76	0.77	0.79
148	Tonga	78	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
149	Trinidad and Tobago	95	0.46	0.44	0.42	0.42	0.42	0.42	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.35	0.35	0.36	0.36	0.36	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.38	0.38	0.38	0.38
150	Tunisia	84	1.28	1.26	1.24	1.22	1.18	1.15	1.11	1.06	1.02	0.98	0.95	0.93	0.90	0.88	0.85	0.84	0.83	0.82	0.81	0.80	0.78	0.77	0.77	0.76	0.75	0.73	0.72	0.70	0.69	0.69
151	Turkey	112	14.00	13.60	13.19	12.71	12.29	11.89	11.50	11.06	10.58	10.41	10.36	10.33	10.16	9.87	9.52	9.14	8.94	8.87	8.76	8.51	8.37	8.18	7.94	7.81	7.62	7.60	7.44	7.15	7.08	7.07
152	Turks and Caicos Islands	29	0.28	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26
153	Tuvalu	77	0.26	0.26	0.26	0.25	0.25	0.25	0.26	0.26	0.25	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.24	0.23	0.22	0.21	0.19	0.20	0.19	0.18	0.18	0.17	0.15	0.13
154	Ukraine	34	1.91	1.84	1.77	1.72	1.65	1.60	1.56	1.51	1.42	1.36	1.35	1.37	1.38	1.39	1.39	1.39	1.40	1.40	1.40	1.40	1.38	1.33	1.30	1.28	1.26	1.23	1.21	1.21	1.20	1.17
155	United Arab Emirates	64	1.30	1.28	1.27	1.25	1.23	1.22	1.20	1.18	1.15	1.12	1.09	1.06	1.04	1.01	0.98	0.95	0.92	0.89	0.86	0.82	0.78	0.74	0.72	0.69	0.67	0.65	0.63	0.61	0.60	0.59
156	United Kingdom	260	37.19	36.35	35.26	34.21	33.51	32.63	31.66	30.51	29.31	28.18	27.36	26.56	25.88	25.42	24.94	24.23	23.76	23.19	22.65	21.80	21.20	20.76	20.45	20.17	20.01	20.03	19.97	19.57	19.27	19.24
157	United States	557	121.25	119.56	117.77	116.05	113.69	111.58	109.85	108.09	106.63	105.45	104.28	102.92	101.53	100.39	99.25	98.48	97.93	97.28	97.01	96.76	96.64	96.28	95.98	95.48	94.82	94.50	94.01	93.52	93.48	93.56
158	Uruguay	45	2.36	2.25	2.17	2.08	2.01	1.93	1.85	1.78	1.74	1.69	1.67	1.60	1.54	1.49	1.43	1.38	1.33	1.27	1.20	1.18	1.15	1.14	1.12	1.10	1.06	1.01	0.94	0.90	0.86	0.84
159	Vanuatu	62	0.14	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.08
160	Venezuela, RB	116	6.22	6.17	6.09	6.01	5.93	5.84	5.75	5.63	5.57	5.45	5.33	5.19	5.07	4.87	4.65	4.40	4.18	3.99	3.75	3.58	3.47	3.27	3.06	2.86	2.53	2.37	2.27	2.20	2.17	2.09
161	Vietnam	121	38.62	38.61	38.51	38.26	38.06	37.85	37.61	37.37	37.13	36.81	36.50	36.14	35.77	35.33	34.64	33.95	33.20	32.48	31.73	30.74	29.81	28.96	28.18	27.26	26.59	25.95	25.33	24.72	24.10	23.28
162	Virgin Islands (U.S.)	36	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
163	West Bank and Gaza	26	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
164	Yemen, Rep.	63	4.38	4.31	4.28	4.24	4.18	4.11	4.02	3.95	3.88	3.82	3.80	3.76	3.75	3.73	3.72	3.68	3.65	3.59	3.49	3.39	3.32	3.21	3.04	2.79	2.52	2.32	2.14	2.05	2.06	2.03

Chapter 3 New Evidence of Energy-Growth Nexus from Inclusive Wealth

3.1 Introduction

Access to reliable and affordable energy is essential not only for supporting basic human needs but also for creating human well-being. The central role of energy and its sustainability has also been recognized in the United Nation’s sustainable development goals. However, the pattern of world energy consumption in the past tends to be unsustainable since it is highly associated with the rapid exhaustion of natural resources and environmental pollution. Energy consumption has been a predominant source of climate change, accounting for more than 60 percent of total global greenhouse gasses (GHG) emission. This trend is expected to increase along with the growing population and increasing economic activity, particularly for developing countries (IEA, 2015). The negative impact of energy consumption and/or economic development on environmental quality has led to a quandary over whether to boost economic growth as high as possible by encouraging higher energy consumption, or giving precedence to environmental sustainability by curbing energy consumption which might result in lower economic growth (Antonakakis et al., 2017).

The environmental Kuznets curve (EKC) hypothesis, on the other hand, argues that environmental sustainability can be achieved without restraining economic development. The EKC hypothesis suggests the existence of a turning point in the economy subsequent to which the increasing trend in environmental degradation will be reversed (see Grossman and Krueger (1991) for rationale behind the EKC hypothesis). The composition and technical effects of the economy will decouple economic growth from GHG emissions through the introduction of renewable energy sources in the energy mix, investment in new and cleaner energy technologies, and adoption of more stringent environmental regulations. As a result, environmental damages that occurred in the earlier stages of development will be ameliorated, and further economic growth will lead to a better environmental quality. Although the EKC hypothesis proposes a promising concept for sustainability, it has some caveats worth mentioning. For instance, the estimated turning point of the EKC might exist at very high levels of income per capita, which are difficult or even impossible to achieve (Bölük and Mert, 2015; Jalil and Mahmud, 2009; Sugiawan and Managi, 2016). Additionally, De Bruyn et al. (1998) and Sugiawan et al. (2017), among others, argue that over the long term, new pollutants and environmental problems might appear, creating a secondary turning point in the economy so that the declining trend in the income-environmental quality relationship will revert back to its former trend.

In addition to the EKC hypothesis, which aims to investigate whether economic development can be detached from environmental degradation, assessment on the sustainability of economic development involves massive literature on energy-growth nexus, which seeks to scrutinize the decoupling between energy consumption and economic growth (Hajko et al., 2018). In the framework of sustainability, energy and environmental conservation policies should be implemented in such a way so as not to hinder economic growth and maintain the utility of future generations from declining. In this respect, numerous studies have investigated the energy-growth nexus by using the per capita income level as a proxy, aiming to find whether energy consumption leads to, is neutral to or is driven by economic development (see for instance Ozturk (2010), Wolde-Rufael (2014), Karanfil and Li (2015), Omri et al. (2015), Koçak and Şarkgüneşi (2017) and Menegaki and Tugcu (2017)). Such empirical literature examines the widely known energy-growth causality relationship hypotheses, i.e., growth, conservation, feedback, and neutrality hypotheses. An energy dependent economy is depicted by either a growth or feedback hypothesis, implying that energy is a stimulus for economic growth. Hence, higher economic growth can be achieved by increasing the level of per capita energy consumption, and vice versa. This type of economy tends to be unsustainable because it is usually characterized by the extensive use of non-renewable energy resources and increasing trend in GHG emissions (Gaspar et al., 2017). On the other hand, a more sustainable economy can be found if either conservation or neutrality hypotheses hold true (Menegaki and Tugcu, 2017). These types of energy-growth relationships suggest that energy and environmental conservation policies, aiming to reduce GHG emissions and high dependency on fossil fuels, might be pursued without adversely affecting the economy.

Most of the aforementioned literature attempts to evaluate the sustainability of economic development by using gross domestic product (GDP) as a proxy for well-being. However, Mumford (2016) argues that such approaches are not reliable, since flow variables such as GDP are only a measure of current, but not intergenerational, well-being. Furthermore, Gaspar et al. (2017) argue that good indicators of well-being need to take into account the quantification of environmental damage and social welfare. Hence, using GDP as a measure of sustainability is inadequate and might be misleading. Several authors, including Arrow et al. (2012), UNU-IHDP (2015) and Managi and Kumar (2018), have proposed a comprehensive measure of well-being, which is referred to as inclusive wealth (*IW*). *IW* offers a novel method for quantifying, measuring and tracking sustainability by comprehensively measuring the productive base of the economy based on three types of capital assets of the nations, i.e., produced, human and natural capital, and aggregates them into a single measure of wealth. These have been the motivation of our work. Our paper aims to investigate the impact of energy consumption on wealth creation in the *IW* framework by using both the generalized method of moments (GMM) estimators, which was developed by Arellano and Bond (1991), and system GMM, which was developed by Blundell and

Bond (1998). We carry out the analyses on both aggregate and disaggregate values of capital assets. We also predict how the *IW* of nations will progress in the next three decades. For this purpose, we rely on a machine learning approach known as model trees because machine learning is known to provide better predictive accuracy compared to the parametric and semi-parametric models (Athey and Imbens, 2017; Mullainathan and Spiess, 2017).

3.2 Empirical strategy

Economic development is not only about achieving higher income growth in terms of per capita GDP but also about creating sustainable well-being (Costanza et al., 2009; Costanza et al., 2014; Klugman et al., 2011). GDP and well-being are two different terminologies that cannot be used interchangeably, although there are some cases, particularly in less developing countries, where GDP does reflect the true well-being provisionally (Weitzman, 2016). Costanza et al. (2009) argue that this temporal correlation between GDP and well-being is understandable because there exists a threshold in the economy beyond which increasing income will be counterbalanced by surfacing costs which are associated with environmental damage and natural capital depletion. However, for more than 70 years, GDP has been inappropriately used as the main indicator for measuring the progress toward the well-being of a nation. As a result, the impact of economic development on well-being of a nation is far beyond expectation because most countries' national development policies have mainly focused only on sustaining GDP growth (Costanza et al., 2009). For instance, Arrow et al. (2012) show that although national economies throughout the globe grow rapidly, their growth is followed by the depletion of natural resources and environmental degradation. They add that such a type of development trajectory tends to be unsustainable, since economic growth fails to maintain the well-being over time.

The shortcoming of GDP for gauging well-being is foreseeable because GDP is only a measure of economic quantity, not quality (Costanza et al., 2009). Additionally, well-being is a complex multidimensional concept, involving not only income and economic activity but also other tangible and intangible assets, such as human capital, social capital, and environmental services (Costanza et al., 2014; Giannetti et al., 2015; Kovacic and Giampietro, 2015; Managi and Kumar, 2018; Mumford, 2016). Therefore, Managi and Kumar (2018) suggest that well-being should be measured based on a set of capital stocks, rather than flow, which form the productive base of economy. Additionally, Gaspar et al. (2017) argue that a good indicator of well-being also need to take into account the quantification of environmental damage and social welfare. Therefore, instead of using GDP, some previous studies (see for instance Hamilton and Hepburn (2014), Managi and Kumar (2018) and Weitzman (2016)) suggest the use of wealth as a measure of progress toward the well-being of a nation. Wealth, according to Hamilton and Hepburn (2014) is defined as "stock of assets that can generate future income and well-being". Consequently, in the light of sustainability, the focus of economic development needs to shifted, from boosting current GDP by consuming wealth to creating new wealth for sustaining well-being.

Many studies have proposed alternative indicators beyond GDP for measuring wealth and tracking the sustainability of economic development. The literature is divided into two main approaches. The first approach attempts to make the GDP greener, either by offering a more comprehensive system of national accounts (SNA) that includes both marketed and non-marketed resources or by combining GDP with another set of social indicators with arbitrarily chosen weights. For instance, Hamilton (1994) and Asheim (2000) proposed a concept of green GDP by making a more comprehensive measure of the economic system that includes natural resources depletion and environmental damages into the SNA. Another example is the human development index (HDI), which was initiated in the early 1990s by Mahbub ul Haq and Amartya Sen to overcome the shortcoming of GDP in measuring the progress of human development. The HDI is a composite index that is constructed by aggregating GDP with two other dimensions of wealth, i.e., health and education, into a single measure (Klugman et al., 2011).

In the second approach, indexes of well-being are measured directly. Such an approach assumes that well-being is independent of GDP; hence, rather than measuring economic activity, it measures changes in environmental, social, and human capital. For instance, the ecological footprint (EF), which was introduced in 1990s by Mathis Wackernagel and William Rees, attempts to assess sustainability by tracking the past and current human activities in exploiting ecological assets and compare this to the Earth's regenerative capacity. Sustainability is achieved if the rates of natural resources extraction and waste emission does not exceed the Earth's biophysical limits to naturally regenerate resources and assimilate waste (Mancini et al., 2016).

However, initiatives to find alternatives to GDP for gauging sustainability are not without flaws. For instance, despite the remarkable contribution of HDI in portraying the progress of human development, it overlooks the ecological dimensions of sustainable development and disregards social goods in capital accounts to complement GDP (UNU-IHDP, 2015). Furthermore, Mumford (2016) argued that instead of measuring the flow of current well-being as green GDP and HDI do, sustainability should be evaluated based on measurement of stock capital assets that form the productive base of economy over time, which reflects intergenerational well-being. Hence, in terms of sustainability, these two alternatives still have noteworthy drawbacks and cannot be used for properly evaluating the sustainability of economic development. In terms of the EF, most of the critiques talk about the relevancy, accuracy and inadequacies of the EF methodology to track all relevant environmental pressures, leading to distorted results and harmful policies (see, for instance Galli et al. (2016) for a detailed discussion about persistent debate on the concept of EF).

The *IW* framework (Arrow et al., 2012; Dasgupta et al., 2015; Managi and Kumar, 2018; UNU-IHDP, 2015) offers a new approach to assess sustainability by measuring stock variables, which are related to the potential intergenerational well-being. Although it is difficult to be measured directly, intergenerational well-being can be determined from the productive base that is used to produce the goods and services that determine current well-being (Kurniawan and Managi, 2017; Mumford, 2016). *IW* provides a comprehensive monetary valuation of wealth in terms of the productive base of the economy, involving three types of capital assets of nations, produced, human and natural capital, and aggregates them into a single measure of wealth (Managi and Kumar, 2018). The valuation of produced capital covers all types of man-made infrastructure such as roads, buildings, and machines. Additionally, accounting of human capital includes population, knowledge and skill from education, and health. For the case of natural capital, although it does not cover the whole ecosystem services, the monetary valuation of natural capital has included both renewable and non-renewable resources, namely forest resources, fisheries, agriculture land, fossil fuels and minerals (Islam et al., 2018; Managi and Kumar, 2018).

Growth in the productive base of economy is a necessary but not sufficient condition for increasing intergenerational well-being (Dasgupta and Mäler, 2000). Hence, increasing *IW* is not a guarantee that sustainability will be achieved; however, it is only a statement about the potential intergenerational well-being, implying that future generations will have a larger productive base of economy for improving their well-being (Mumford, 2016). Additionally, sustainability in the framework of *IW* does not require that every type of capital has to be sustained. Hence, a decline in one type of capital stock is allowed, as long as it is sufficiently compensated by increasing the social value of other types of capital (Managi and Kumar, 2018; UNU-IHDP, 2015). For instance, consuming non-renewable natural resources such as fossil fuels and minerals for producing economic output today will reduce the stock of natural capital in the future. Therefore, to maintain the total wealth in the future, this loss needs to be compensated by sufficient increase in either produced or human capital such as increasing number of schools and health facilities that will enhance the capabilities of human capital to generate more income in the future. However, Barbier (2015) highlights the structural imbalance in most economies, which is attributed to the underpricing of natural capital. As a result, the net proceeds from natural capital conversion are not sufficient enough for making new substantial investments in produced and human capital. This has resulted in massive exploitation of natural resources in an unsustainable manner.

The aforementioned explanations imply that the transition toward a more sustainable economy requires a substantial shift from non-renewable to renewable energy sources (Dincer, 2000; Kaygusuz, 2012). The *IW* framework has also recognized the indispensable role of renewable energy toward sustainability in its accounting system and demonstrates that the substitution of renewable for non-renewable energy sources is indeed sustainable (Managi and Kumar, 2018). For this purpose, the *IW* framework adopts the concept of renewable energy capital to capture investment in renewable energy facilities, such as solar and wind power plants (see for instance Yamaguchi and Managi (2019) for a detailed discussion about renewable energy capital). It is intriguing to note that the *IW* framework considers renewable energy capital as a part of produced capital, instead of being included in natural capital. The main reason behind this uncommon classification is that because renewable energy facilities have a closer resemblance to produced capital. However, unlike non-renewable energy facilities, input for renewable energy facilities comes from renewable resources that will substitute the use of non-renewable resources such as oil and gas (Managi and Kumar, 2018).

In the past few decades, literature on sustainability has also involved extensive research on the energy-growth nexus, aiming to study the decoupling between energy consumption and economic development. However, the results remain inconclusive due to different samples, empirical methodologies, or both. The literature has identified four testable hypotheses on the possible energy-income relationship (see for instance Ozturk (2010), Wolde-Rufael (2014), Karanfil and Li (2015), Omri et al. (2015), Koçak and Şarkgüneşi (2017) and Menegaki and Tugcu (2017)). First, the *growth hypothesis* postulates that there is a unidirectional causality running from energy consumption to economic growth. This hypothesis indicates an energy dependent economy where energy is a stimulus for GDP growth, implying that a shortage of energy may negatively affect economic growth or may cause poor economic performance. Second, the *conservation hypothesis* postulates that there is a unidirectional causality running from economic growth to energy consumption. This type of relationship indicates a less energy dependent economy, suggesting that energy conservation policies may be implemented with little or no adverse effect on the GDP. The third hypothesis is the *feedback hypothesis* that postulates that there is a bidirectional causal relationship between energy consumption and economic growth. This interdependence suggests that energy consumption and economic growth are interrelated and act as complements to each other. The fourth hypothesis is the *neutrality hypothesis,* suggesting that there is no causal relationship between energy consumption and economic growth. In this view, energy consumption does not influence economic growth and vice versa. Similar to the conservation hypothesis, this type of relationship also implies a more sustainable economy, where energy conservation policies may be pursued without adversely affecting the economy.

Unlike previous studies, this paper focuses on investigating the impact of energy consumption on the sustainability of economic development by using *IW* as the proxy for intergenerational well-being.

To the best of our knowledge, this is the first study that investigates the sustainability of energy consumption in the *IW* framework. This study is our first, and perhaps the most important, contribution to the literature. Additionally, in contrast to previous studies that have mainly focused on granger causality analysis, we employ the GMM estimators, which were developed by Arellano and Bond (1991), and system GMM, which was developed by Blundell and Bond (1998), to explore the impact of energy consumption on the formation of capital assets. We prefer to use the GMM estimators to address autocorrelation and endogeneity issues that might arise from our model and data. Additionally, in regard to the secondary objectives of our paper to forecast the growth of *IW*, we rely on a relatively new technique of machine learning known as regression trees. Compared to most parametric and semi-parametric models, this technique shows a better predictive performance in terms of root mean squared error, particularly if the sample size or the number of predictor variables is large (Athey and Imbens, 2017; Mullainathan and Spiess, 2017). To improve the predictive performance of a simple regression tree, we employ two methods. The first method, boosted regression trees (BRT), improves the predictive performance of a regression tree by boosting (an adaptive method for combining many simple models) (Elith et al., 2008; Persson et al., 2017). The second method is the model trees, which improved the predictive performance of a regression tree by replacing the leaf nodes with regression models (Wang and Witten, 1996).

3.3 Methodology: Parametric and non-parametric analysis

Our analysis involves a balanced panel of 104 countries over the period 1993–2014. The time span and selection of countries used were constrained by the availability of data. As a proxy of wealth, this paper employs the *IW* data from the 2014 and 2018 Inclusive Wealth Report (Managi and Kumar, 2018; UNU-IHDP, 2015), which is measured in constant 2005 US dollars. We also include the disaggregated data of *IW* in terms of produced capital (PC), human capital (HC) and natural capital (NC) in our analysis. Additionally, we also utilize some development indicators from the World Bank World Development Indicators of 2017 as predictors, including per capita energy consumption, which is measured in kilograms of oil equivalent; per capita GDP, which is measured in constant 2010 US dollars; and population density, which is measured in people per square kilometer of land area. All variables are expressed in natural logarithms. The descriptive statistics and correlation matrix of the variables are provided in Table 3.1.

Table 3.1 Descriptive statistics and correlation matrix

Descriptive Statistics	***ln IW***	***ln PC***	***ln HC***	***ln NC***	***ln GDP***	***ln EC***	***ln POP***
Minimum	9.634	4.224	6.330	3.743	5.131	4.813	0.4339
1st Quartile	10.830	8.190	10.060	8.381	7.451	6.329	3.1464
Median	11.630	9.342	10.930	9.144	8.533	7.092	4.3534
Mean	11.660	9.430	10.900	9.296	8.658	7.229	4.1136
3rd Quartile	12.450	10.960	11.580	10.080	10.010	8.153	5.0629
Maximum	14.080	12.410	13.800	13.900	11.630	9.742	8.6290
Std. Deviation	0.968	1.698	1.163	1.578	1.488	1.059	1.437
Correlation Matrix							
ln *IW*	1	-	-	-	-	-	-
ln *PC*	0.3227	1	-	-	-	-	-
ln *HC*	0.7928	0.0522	1	-	-	-	-
ln *NC*	0.4047	0.1932	-0.0161	1	-	-	-
ln *GDP*	0.3513	0.9660	0.0807	0.2017	1	-	-
ln *EC*	0.3989	0.8761	0.1325	0.2705	0.8923	1	-
ln *POP*	-0.1540	-0.2797	-0.0513	-0.0686	-0.2504	-0.2129	1

The 2014 *IW* Report (UNU-IHDP, 2015) shows that during the period 1993-2011, more than 80 percent of the evaluated countries show positive average growth in GDP per capita; however, only 60 percent of the countries experienced gains in per capita *IW*. The positive growth of *IW* mainly results from the growth of human capital, which contributed to approximately 55 percent of overall gains in *IW*. At the same time, the contributions of produced and natural capital are only approximately 32 percent and 13 percent, respectively. From Figure 3.1, we can see that the growth of per capita *IW* cannot be detached from the level of energy consumption and GDP per capita. In general, countries with high per capita energy consumption but relatively low GDP per capita tend to experience a declining *IW* per capita (marked by red triangles). On the other hand, gains in per capita *IW* (marked by green triangles) can be found in countries that have a higher ratio of per capita GDP to energy consumption. These facts provide us with preliminary information about the energy-wealth relationship, suggesting that the growth of per capita *IW* is correlated with the efficient use of energy. In the next section, we will explore this relationship further by using more reliable statistical methods to obtain robust inferences from our data.

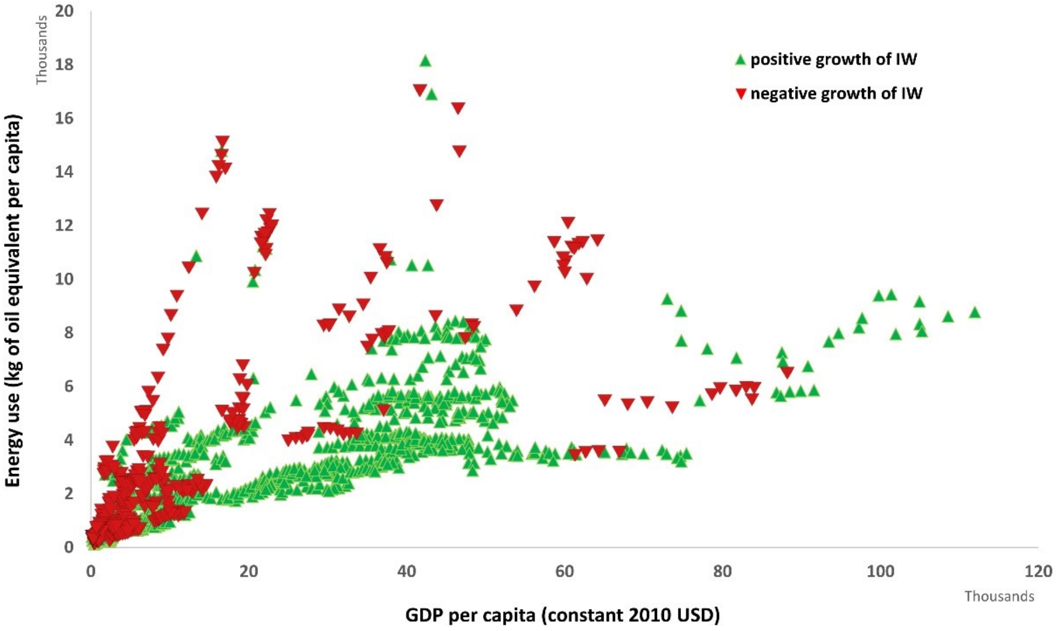


Figure 3.1 Changes in global *IW* per capita for 1993-2014

Our paper studies the relationship between energy consumption and wealth based on the following parametric equations:

$$\ln IW_{it} = \alpha_0 + \alpha_1 \ln IW_{it-1} + \alpha_2 \ln EC_{it} + \alpha_3 \ln GDP_{it} + \alpha_4 \ln POP_{it} + \varepsilon_{it} \quad (3.1)$$

$$\ln PC_{it} = \beta_0 + \beta_1 \ln PC_{it-1} + \beta_2 \ln EC_{it} + \beta_3 \ln GDP_{it} + \beta_4 \ln POP_{it} + \varepsilon_{it} \quad (3.2)$$

$$\ln HC_{it} = \gamma_0 + \gamma_1 \ln HC_{it-1} + \gamma_2 \ln EC_{it} + \gamma_3 \ln GDP_{it} + \gamma_4 \ln POP_{it} + \varepsilon_{it} \quad (3.3)$$

$$\ln NC_{it} = \delta_0 + \delta_1 \ln NC_{it-1} + \delta_2 \ln EC_{it} + \delta_3 \ln GDP_{it} + \delta_4 \ln POP_{it} + \varepsilon_{it} \quad (3.4)$$

where IW is the per capita inclusive wealth; PC is the per capita produced capital; HC is the per capita human capital; NC is the per capita natural capital; EC is the per capita energy consumption; GDP is the per capita GDP; and ε_{it} is the standard error term. Furthermore, UNU-IHDP [18] show a strong correlation between population growth and declining wealth per capita. Hence, to avoid omitted variable bias, our models also include population density (POP) as an independent variable. We also include the lags of the dependent variables on the right-hand side of equations (1) to (4) based on our assumption that the current year's wealth is highly influenced by its previous year's value.

The presence of these lagged dependent variables as regressors leads to so-called dynamic panel bias (Roodman, 2006). We also need to anticipate the issue of endogeneity due to the possible feedback effect from wealth to either GDP or energy consumption. Therefore, instead of using ordinary fixed or random effects panel data model, our model will be estimated using the GMM estimators. Arellano and Bond (1991) showed that GMM estimators can handle the issues of autocorrelation and endogeneity that might arise from our model by treating each variable as endogenous and instruments the variables by their own lag. However, Blundell and Bond (1998) argued that the Arellano and Bond (1991) estimator is likely to suffer from a weak instruments problem, particularly if the regressors display persistence over time. Therefore, they suggested the use of system GMM in which the moment conditions in the differenced model and levels model are combined. We use both the Arellano-Bond and system GMM estimators for our analysis. Furthermore, to ensure the robustness of our models, we need to test the validity of the instruments and the presence of autocorrelation in our models. For this purpose, we conduct the Hansen test of over-identification and the Arellano-Bond test for second order and higher-order serial correlation (AR(2) test). The Hansen test has a null hypothesis of ‘the instruments as a group are exogenous’, while the Arellano–Bond test for autocorrelation has a null hypothesis of no autocorrelation and is applied to the differenced residuals (Apergis and Ozturk, 2015).

For forecasting purposes, instead of using the parametric models, our paper relies on non-parametric machine learning methods known as regression trees. To improve the predictive performance of a single tree, we use the BRT technique and model trees. The BRT technique combines two types of algorithms, i.e., regression trees and boosting, aiming to improve the performance of a single regression tree model by growing many trees, fitting them, and combining them to minimize error. The fitting procedure involves optimizing three parameters simultaneously, i.e., the number of trees, learning rate, and tree complexity (Elith et al., 2008). The number of trees indicates the number of trees that are used to form the linear combination of the final BRT model. The learning rate indicates how much the contribution of each tree will be reduced as it is added to the model, while tree complexity indicates the number of nodes in a tree. Additionally, to improve the model’s accuracy and reduce overfitting, we can also introduce a stochastic term into our model by setting the value of the bag fraction. Unlike the BRT technique, which attempts to grow many trees, a model tree attempts to improve the accuracy of a regression tree by replacing the single value of leaf nodes with linear regression models. As a result, we can improve the predictive performance of regression trees while maintaining their simplicity (Lantz, 2013).

3.4 The impact of energy consumption on *IW* growth

Table 3.2 provides the estimation results of our model. The first column shows the impacts of energy consumption on *IW*, while the second, third and fourth columns present the impact of energy consumption on produced, human and natural capital, respectively. From the results of the Hansen and Arellano-Bond tests, we confirm the validity of the instruments, and we find no evidence of second or higher-order serial correlation in the first-differenced residuals for all cases.

We first examine the impact of energy consumption on wealth creation, which is the main focus of this paper. As seen in Table 3.2, both the Arellano-Bond and system GMM estimators show that energy consumption has a negative influence on *IW* growth. In the short-run, a 1 percent increase in energy consumption leads to a decline in per capita *IW* for approximately 0.0018 percent for the Arellano-Bond estimator, and 0.0378 percent for the system GMM estimator. If we carry out our analysis further, then we can see various impacts of energy consumption on disaggregated capital formation. While it provides beneficial impacts on increasing human capital, higher energy consumption leads to the depletion of natural resources. Additionally, we see no significant impacts of energy consumption on produced capital. These results suggest that the declining level of natural capital, which is caused by increasing energy consumption, is not sufficiently compensated by the socio-economic gain in energy consumption in the form of produced and human capital. Accordingly, the net effect of energy consumption on the productive base of the economy is negative, suggesting that the current pattern of energy consumption is not sustainable. Our findings support the earlier results from Gaspar et al. (2017) and Menegaki and Tugcu (2017) that found a negative impact of energy consumption on sustainability by using the Index of Sustainable Economic Welfare as a proxy of wealth.

We continue our analysis on population growth. Although we find no significant impact of population growth on per capita *IW* for both estimators, population growth shows a positive and significant impact on produced capital. Additionally, we find that population growth exerts a

Table 3.2 The impact of energy consumption on wealth creation

Variables	ln IW		ln PC		ln HC		ln NC	
	Arellano-Bond	***Blundell-Bond***	***Arellano-Bond***	***Blundell-Bond***	***Arellano-Bond***	***Blundell-Bond***	***Arellano-Bond***	***Blundell-Bond***
ln IW_{t-1}	0.9475	0.9802	-	-	-	-	-	-
	(0.0025)***	(0.0146)***						
ln PC_{t-1}	-	-	0.9986	0.9419	-	-	-	-
			(0.0020)***	(0.0276)***				
ln HC_{t-1}	-	-	-	-	0.9469	0.9912	-	-
					(0.0014)***	(0.0018)		
ln NC_{t-1}	-	-	-	-	-	-	0.7842	0.9826
							(0.0036)***	(0.0147)***
ln EC	-0.0018	-0.0378	-0.0034	-0.0034	0.0047	0.0005	-0.0094	-0.0971
	(0.0011)*	(0.0123)***	(0.0021)	(0.0379)	(0.0002)***	(0.0059)	(0.0006)***	(0.0460)**
ln GDP	0.0288	0.0390	0.1377	0.0875	0.0011	0.0001	0.0312	0.0802
	(0.0016)***	(0.0077)***	(0.0030)***	(0.0426)***	(0.0004)***	(0.0047)	(0.0030)***	(0.0314)**
ln POP	-0.0052	-0.0015	0.0949	0.0548	-0.0003	0.0020	-0.3407	0.0011
	(0.0044)	(0.0143)	(0.0112)***	(0.0218)**	(0.0009)	(0.0043)	(0.0091)***	(0.0217)
Diagnostic tests								
AR (2) test	-0.7427	-0.9000	-0.3000	-0.8100	0.9062	0.8300	0.0072	-0.6400
	[0.4577]	[0.3670]	[0.7641]	[0.4150]	[0.3648]	[0.4070]	[0.9942]	[0.5240]
Hansen test	89.6506	86.8100	89.6350	90.9500	91.1620	97.7100	97.1346	79.2300
	[0.2896]	[1.0000]	[0.2900]	[1.0000]	[0.2530]	[1.0000]	[0.1735]	[1.000]

Notes:

1. ***, ** and * denote statistical significance at 1, 5 and 10 percent levels, respectively
2. Standard errors in parentheses; p-values in brackets

negative pressure on the environment, causing a decline in natural capital. Our findings imply that uncontrolled population growth is unfavorable for sustainability. This result is not unexpected. A growing population requires additional resources for satisfying basic human needs. Hence, a growing population is likely to place escalating pressures on natural capital. Furthermore, as populations increase, the demand for additional infrastructure for supporting human well-being also increases. Accordingly, a higher population level will lead to increasing produced capital. However, due to economic constraints, produced capital grows at a slower rate than the growth rate of a population, which can be seen from the relatively small coefficient of *lnPOP*, which is only 0.0949 for the Arellano-Bond estimator, and 0.0548 for the system GMM estimator. This scenario will result in social and economic inequalities, which eventually prevent the growing population from providing significant contributions to the increasing human capital. Cumulatively, the impact of population growth on per capita *IW* is neutral. Our finding contradicts the earlier study from Lutz et al. (2017), arguing that a sustainable development path is characterized by a rapid social development and a relatively low population growth. However, our finding supports Casey and Galor (2017), who found that lower population growth leads to a higher environmental quality.

The impact of per capita GDP on sustainability is rather intriguing. We confirm positive and significant impacts of GDP on all types of capital assets. GDP acts as a significant driver of produced, human and natural capital growth, where the highest impact can be found in produced capital. As seen in Table 3.2, a one percent increase in per capita GDP leads to around a 0.14 percent increase in produced capital. This result seems to be obvious since higher economic growth is usually followed by an increasing demand of infrastructure for education, health and for creating a better standard of living. As a result, economic growth will lead to increasing produced and human capital. This finding is consistent with that of Arto et al. (2016), showing a strong correlation between GDP and living standard, although it will decouple at high income levels. The positive impact of GDP on natural capital, on the other hand, might be beyond our expectation, but it is not without explanation. One might expect that economic growth will place continuous pressures on natural capital since increases in output require more inputs. However, economic growth also creates advancement in technology, which leads to the improvement of either extraction or exploration efficiency. Such an effect is captured by the positive and significant impact of economic growth on natural capital. This confirms the earlier study of Sawada and Managi (2014), showing that technological changes affect the efficient extraction of non-renewable resources. Taken as a whole, higher per capita GDP growth convincingly leads to a higher per capita *IW*, suggesting a promising sustainable future.

Next, we aim to forecast the growth of *IW* over the next three decades. For this purpose, we use both the BRT technique and model trees. To assess the accuracy of our models, we spilt our data into training and test sets. The training set consists of 70% randomly selected data, while the rest of the data will be used for quasi out of sample testing. For estimating the BRT model, we use the R programming environment with the add-on package *gbm*, which was developed by Ridgeway (2006), and *dismo*, which was developed by Hijmans et al. (2015). For our estimation, we set the tree complexity equal to five, the learning rate equal to 0.01, and the bag fraction equal to 0.5. At the same time, the optimum number of trees is determined by the *dismo* package using cross-validation. For estimating the model trees, we use the M5-prime (M5P) algorithm, which was developed by Wang and Witten (1996). The M5P algorithm is available in the R programming environment via the *RWeka* package, which was developed by Hornik et al. (2002). We begin our forecasting by calibrating our models using the training set. Afterwards, we assess the predictive performance of our model using the test set.

The summary statistics of our forecast are provided in Table 3.3. We evaluate the goodness of fit of our models based on the correlation coefficients, mean absolute error (MAE) values and comparison of summary statistics between the predicted and true values. First, the correlation coefficient indicates how well the predicted values correspond to the true values, ranging between -1 and +1. A correlation close to these extreme values indicates a perfectly linear relationship, while near zero values indicate the absence of a linear relationship (Lantz, 2013). Our models show a very high correlation coefficient of 0.999 for all cases, suggesting a strong association between the predicted and the true values. Furthermore, to measure how far off our predictions are from the actual data, we need to examine the MAE values. The relatively small MAE values for all cases suggest that both methods demonstrate a fairly good predictive performance. However, the M5P model trees outperform the technique by providing smaller MAE values. Finally, we also need to check the summary statistics to evaluate the agreement between the predicted and true values. In general, our models show a good predictive performance between the first and third quartiles, but they fail to accurately predict the extreme values of the data. Hence, their predictions fall on a slightly narrower range than the true values. Once again, the M5P model trees outperform the BRT technique by providing more accurate predictions.

The summary statistics in Table 3.3 provide clear evidence that the M5P model trees is more superior than the BRT technique; hence, we will use the M5P model trees for out of sample forecasting. For this purpose, we use the world population prospect of the United Nations to obtain the projected global population growth until 2050. Additionally, we assume that the global economy grows at a constant rate of 2.6 percent per annum. We use three different scenarios for the annual growth of the world's per capita energy consumption, i.e., 0.5, 1.0 and 1.5 percent per annum. The summary of our forecasts is presented in Figure 3.2 and Figure 3.3.

Table 3.3 Predictive performance of BRT model

Summary Statistics	***ln IW***			***ln PC***		
	Actual	***BRT***	***M5P***	***Actual***	***BRT***	***M5P***
Minimum	9.641	9.663	9.639	4.224	4.615	4.248
1st Quartile	10.846	10.846	10.846	8.095	8.076	8.098
Median	11.688	11.683	11.683	9.381	9.360	9.363
Mean	11.692	11.692	11.692	9.446	9.448	9.446
3rd Quartile	12.457	12.452	12.453	11.028	11.063	11.039
Maximum	14.010	13.961	13.997	12.388	12.336	12.401
MAE	-	0.009	0.009	-	0.023	0.018
Correlation	-	0.999	0.999	-	0.999	0.999

Summary Statistics	***ln HC***			***ln NC***		
	Actual	***BRT***	***M5P***	***Actual***	***BRT***	***M5P***
Minimum	6.357	6.419	6.357	4.095	4.029	4.122
1st Quartile	10.092	10.088	10.090	8.359	8.366	8.364
Median	10.935	10.931	10.932	9.118	9.113	9.114
Mean	10.938	10.939	10.938	9.317	9.315	9.317
3rd Quartile	11.588	11.588	11.589	10.085	10.101	10.102
Maximum	13.676	13.696	13.689	13.897	13.660	13.898
MAE	-	0.008	0.003	-	0.016	0.014
Correlation	-	0.999	0.999	-	0.999	0.999

Figure 3.2 shows the projections of global average per capita *IW* with three different scenarios. From Figure 3.2, we can see that the world's average per capita *IW* is expected to increase in the next three decades, suggesting a potential increase in intergenerational well-being. However, we can also notice that the growth of average per capita *IW* is determined by the level of energy consumption. In line with our parametric models, our forecast models show that a lower growth of per

capita energy consumption leads to a higher growth of average per capita *IW*. Assuming that the economy grows steadily without being driven by energy consumption, we find that reducing the average growth of energy consumption by 1 percent per year will lead to a 1.8 percent increase in average per capita *IW* in the end of our study period.

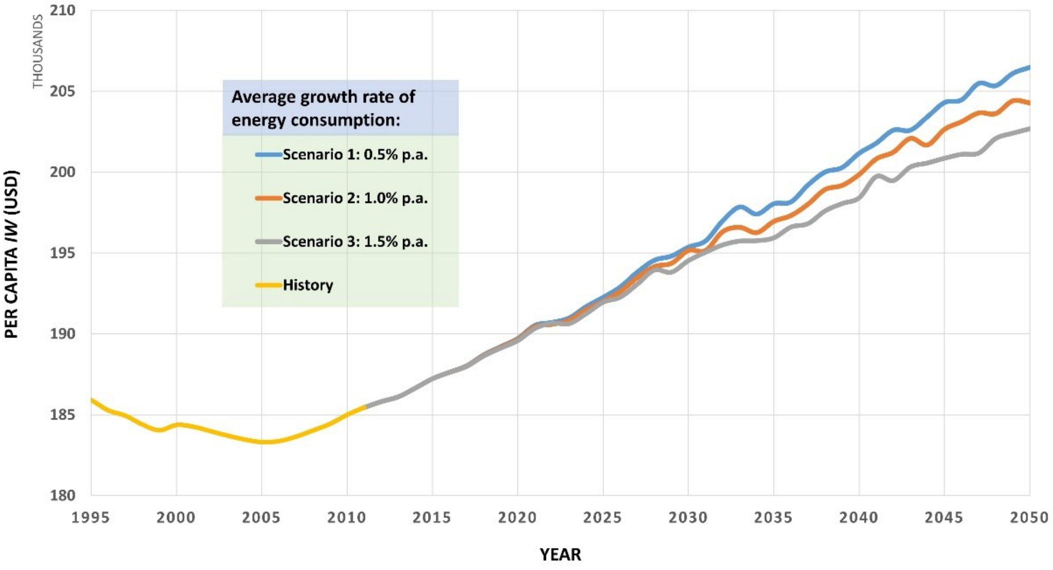
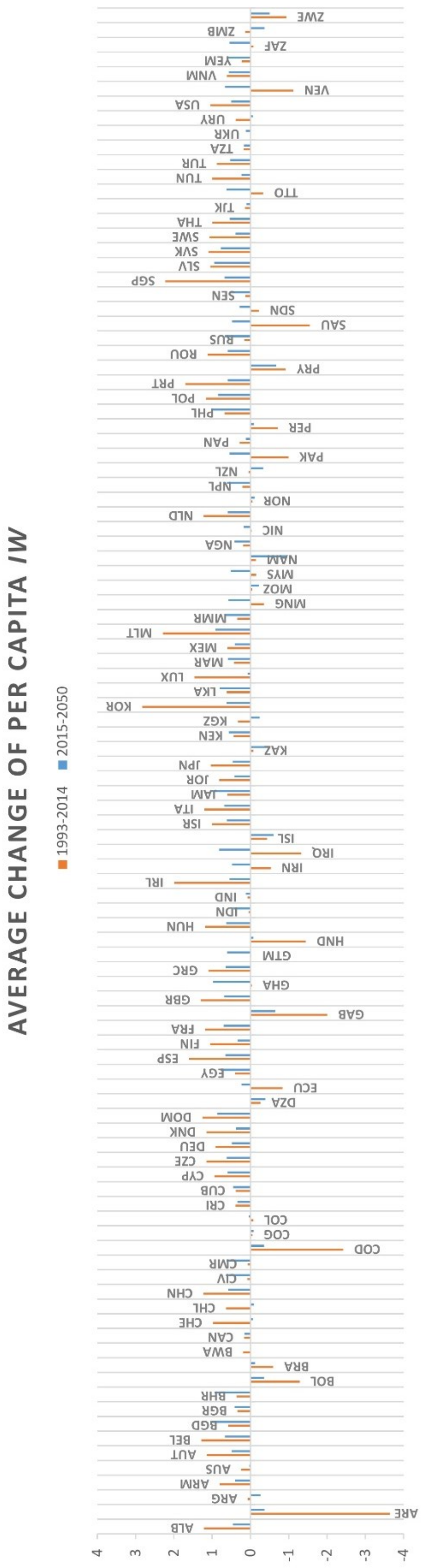
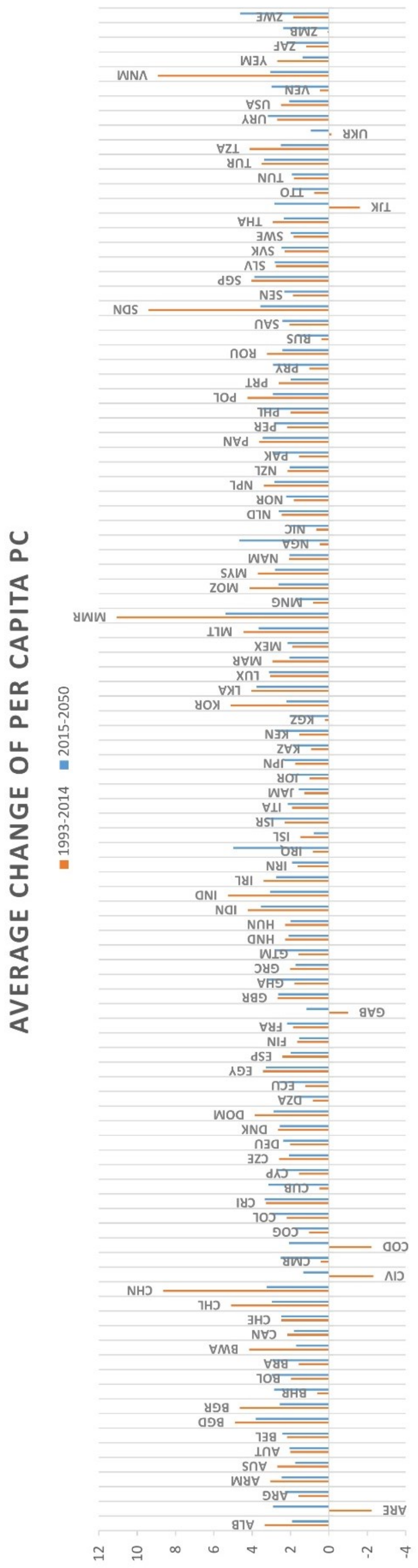


Figure 3.2 Projections of global average per capita *IW*

A more detailed country analysis of the average change of per capita *IW* and capital assets is provided in Figure 3.3. In Figure 3.3, we divided our analysis into two study periods, i.e., the current study period (1993-2014), which is denoted by orange bars, and the future study period (2015-2050), which is denoted by blue bars. As seen in Figure 3.3, in the next three decades, the productive base of the economy grows at a positive rate in more than 76 percent of the countries in our study. This number is higher than the previous study period, where only 70 percent of the countries showed a positive average growth rate of *IW* per capita. Additionally, we also forecast that some countries with a negative average growth of per capita *IW* in the current study period will be able to reduce


AVERAGE CHANGE OF PER CAPITA *IW*
1993-2014
2015-2050
4
3
2
1
0
-1
-2
-3
-4
ALB
ARE
ARG
ARM
AUS
AUT
BEL
BGD
BGR
BHR
BOL
BRA
BWA
CAN
CHE
CHL
CHN
CIV
CMR
COD
COG
COL
CRI
CUB
CYP
CZE
DEU
DNK
DOM
DZA
ECU
EGY
ESP
FIN
FRA
GAB
GBR
GHA
GRC
GTM
HND
HUN
IDN
IND
IRL
IRN
IRQ
ISL
ISR
ITA
JAM
JOR
JPN
KAZ
KEN
KGZ
KOR
LKA
LUX
MAR
MEX
MLT
MMR
MNG
MOZ
MYS
NAM
NGA
NIC
NLD
NOR
NPL
NZL
PAK
PAN
PER
PHL
POL
PRT
PRY
ROU
RUS
SAU
SDN
SEN
SGP
SLV
SVK
SWE
THA
TJK
TTO
TUN
TUR
TZA
UKR
URY
USA
VEN
VNM
YEM
ZAF
ZMB
ZWE


AVERAGE CHANGE OF PER CAPITA PC
1993-2014
2015-2050
12
10
8
6
4
2
0
-2
-4
ALB
ARE
ARG
ARM
AUS
AUT
BEL
BGD
BGR
BHR
BOL
BRA
BWA
CAN
CHE
CHL
CHN
CIV
CMR
COD
COG
COL
CRI
CUB
CYP
CZE
DEU
DNK
DOM
DZA
ECU
EGY
ESP
FIN
FRA
GAB
GBR
GHA
GRC
GTM
HND
HUN
IDN
IND
IRL
IRN
IRQ
ISL
ISR
ITA
JAM
JOR
JPN
KAZ
KEN
KGZ
KOR
LKA
LUX
MAR
MEX
MLT
MMR
MNG
MOZ
MYS
NAM
NGA
NIC
NLD
NOR
NPL
NZL
PAK
PAN
PER
PHL
POL
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PRY
ROU
RUS
SAU
SDN
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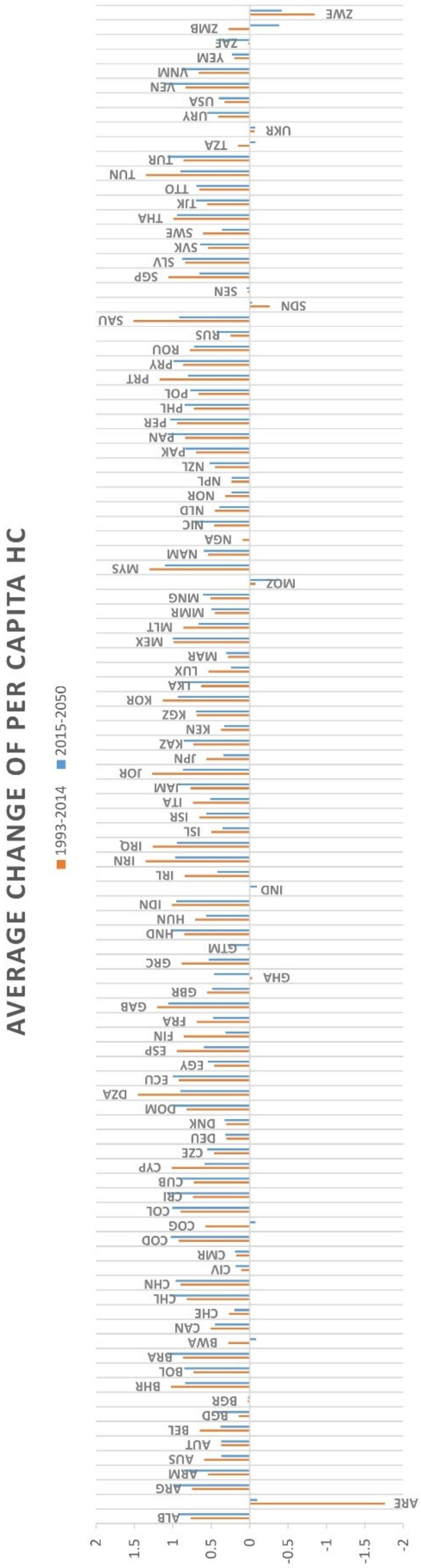

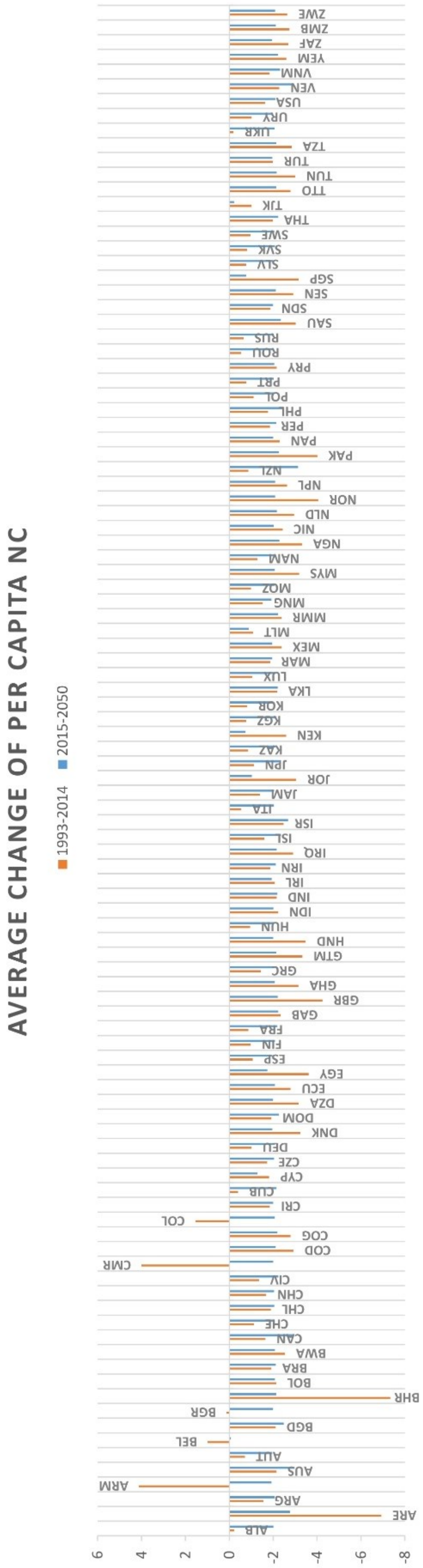

Figure 3.3 Changes in productive base of economy for 1993-2050

the declining rate of *IW* per capita in the next study period. Hence, our finding suggests that the future economy is likely to grow in a more sustainable way.

Although our models forecast a promising sustainable future, this result is not without caution, since growth in the productive base of an economy is dominated by the rapid expansion of produced capital, moderate increase of human capital and steady depletion of natural capital. Additionally, both our parametric and non-parametric models confirm that the current pattern of energy consumption tends to be unsustainable, since attempts to achieve higher per capita *IW* will be hindered by an increasing level of energy consumption. . This is likely due to the domination of fossil fuels in the global energy mix, which in 2015 was accounted for more than 80 percent of total energy consumption. Rapid investment in non-renewable energy facilities to meet the growing demand of energy consumption has led to a significant increase in produced capital. However, such energy facilities would require a large amount of input from non-renewable resources, such as oil and gas. As a result, there will be a significant decline in natural capital alongside produced capital growth, as projected by our model. Furthermore, our models also forecast that the same growth pattern is likely to be observed in the future.

In the light of the SDGs, which aim to ensure universal access to affordable, reliable and modern energy services, these findings corroborate the existence of the so-called ethical dilemma of energy consumption, since many people are currently suffering from lack of access to electricity and clean cooking facilities. In 2016, despite the improving access to electricity in most regions, the number of people who has no access to electricity was estimated around 1.1 billion, accounting for approximately 14 percent of the world's population. Additionally, 2.8 billion people was estimated to have no access to clean cooking facilities (IEA, 2017). Therefore, efforts for improving access to modern energy services are likely to be followed by hypothetical loss of well-being, which is indicated by a lower growth of projected per capita *IW*, unless there are sustained and concerted efforts to make a transition to renewable energy sources. In the *IW* framework, the benefits of making new investment in renewable energy capital are at least threefold. First, investment in renewable energy capital, such as solar panels and wind farms, may positively affect the total *IW* by increasing produced capital because those renewable energy facilities are literally manufactured structures (Managi and Kumar, 2018). Second, unlike conventional fossil fuel power plants which need to be fueled by consuming significant amount of non-renewable natural resources, renewable energy facilities rely on input from renewable natural resources, such as wind and solar. Therefore, the high dependency on fossil fuel might be reduced and the depletion of natural capital can be averted (Managi and Kumar, 2018). Finally, investment in renewable energy capital may also affect the total *IW* positively through increasing health capital, because renewable energy capital is associated with healthier environment compared to that of fossil fuels (see for instance Dincer (2000), Diesendorf and Elliston (2018) and West et al. (2013)).

3.5 Conclusions and policy implications

The objective of this study was to investigate the impact of energy consumption on wealth creation in the inclusive wealth (*IW*) framework and forecast the growth of *IW* over the next three decades. From the estimation results, we found a negative and significant impact of energy consumption on per capita *IW* growth, suggesting an unsustainable pattern of world energy consumption, since higher energy consumption leads to lower growth of per capita *IW* and vice versa. In contrast, economic growth was found to have a significant and favorable impact on the sustainability of economic development by promoting per capita *IW* growth. We also found that uncontrolled population growth was associated with a declining trend in the productive base of economy. Our non-parametric models forecasted that over the next three decades, the average growth of per capita *IW* should increase alongside economic growth. We also found that the number of countries that should follow a sustainable development path would likely increase in the future. However, the growth of per capita *IW* will be hindered by increasing levels of energy consumption and population growth.

Although suggesting new policies is beyond the scope of this paper, our findings highlight some important policy implications. First, our models suggest that energy conservation policies can be promoted without threatening the sustainability of economic development. However, these policies should be enacted carefully due to the possible link between energy consumption and economic growth. If there exists a unidirectional causality from energy consumption to economic growth, then policies aiming to reduce energy consumption will affect *IW* growth both directly and indirectly through GDP growth. Hence, the outcomes of these policies will highly depend on the elasticity between energy consumption-economic growth and energy consumption-*IW* growth. Second, our findings highlight the necessity for increasing the efficiency of energy consumption, which will result in at least two impacts on sustainability. First, the deployment of more energy efficient technologies will directly influence the growth of *IW* by limiting the growth of energy consumption while maintaining the positive growth of economic development. Second, more efficient energy use will increase the productive base of economies by reducing the declining rate of natural capital while increasing the socio-economic gains in produced and human capital. Finally, our findings emphasize that a shift to renewables is a prerequisite for sustainable development since renewable energy capital will positively affect the total wealth by threefold through increasing produced capital, reducing the depletion rate of natural capital and reducing the negative impact of energy use on human capital.

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Chapter 4 Are carbon dioxide emissions reductions compatible with sustainable well-being?

4.1 Introduction

Climate change mitigation has become a primary challenge of the global energy/environmental policy for the last two decades. The threats of extreme climatic events to human and the sustainability of natural ecosystems have urged policymakers to reduce the increasing anthropogenic emissions of greenhouse gasses (GHG), particularly carbon dioxide (CO_2) which contributes to approximately 65 percent of total annual GHG emissions (IPCC, 2014). The first attempt on the international level to reduce anthropogenic CO_2 emissions was made in 1992 with the signing of United Nations Framework Convention on Climate Change (UNFCC). This was followed by the enactment of subsequent international treaty for combating climate change such as Kyoto Protocol, Bali Action Plan, and Copenhagen Acord. In 2015, the 21^{st} Conference of the Parties of the UNFCCC has ratified the Paris Agreement with a legally binding target for limiting global average temperature rise below 2°C (B2C) with respect to pre-industrial levels by the end of the century, to avoid the harmful effects of climate change.

Various mitigation scenarios for achieving the B2C target require substantial reduction of CO_2 emissions. However, with the current trend of CO_2 emissions growth, which is mainly driven by increasing demand of energy consumption and economic activities, the target is somewhat difficult to achieve (IPCC, 2014). Starting from the first *Industrial Revolution*, the demand for energy consumption has increased sharply, leading to the substantial increase of anthropogenic CO_2 emissions from fossil fuel combustion from around zero to more than 32 $GtCO_2$ in 2013 (IEA, 2015). Several previous studies (see, for instance Antonakakis et al. (2017), Fernández-Amador et al. (2017), Marangoni et al. (2017) and

Steckel et al. (2013)) provide undoubted evidence of strong interrelationship between economic development, energy consumption and CO_2 emissions. Their findings suggest that anthropogenic CO_2 emissions reductions can be achieved by restraining per capita energy consumption, although it might pose a serious threat to economic development. This creates an ethical dilemma for policymakers that need to be cautiously compromised, whether to focus on boosting economic development or preserving environmental sustainability (Antonakakis et al., 2017).

The literature of environmental Kuznets curve (EKC), on the other hand, postulates that CO_2 emissions reductions can be achieved without restraining economic development (see for instance Grossman and Krueger (1991), Beckerman (1992) and Panayotou (1993) for the early foundation of the EKC hypothesis). Moreover, the EKC hypothesis suggests that the most feasible and sustainable way to decarbonize the economy is by encouraging further economic development. According to the EKC hypothesis, increasing level of CO_2 emissions is an inevitable impact of economic activities that occurs only temporarily in the early stage of economic development. Once an economy is prosperous enough, the demand for pollution abatement will increase and eventually lead to a decreasing level of CO_2 emissions. However, although the EKC hypothesis proposes a promising concept for de-carbonization pathways, the empirical evidence for its existence remains contentious. For instance, Pao and Tsai (2011), Apergis and Ozturk (2015), Sugiawan and Managi (2016) and Zaman and Moemen (2017) find an inverted U-shaped relationship between economic growth and CO_2 emissions which support the existence of EKC hypothesis. In contrast, some literatures argue that instead of taking the inverted U-shaped curve, the income-CO_2 emission relationship follow either an N-/M-shaped curve (see, for example Ahmed et al. (2017), Pérez-Suárez and López-Menéndez (2015) and Yang et al. (2015), which reject the existence of EKC hypothesis.

Hindrances to achieve the B2C target might also come from the underutilization of renewable energy (RE) sources in most countries' national energy mix policies. The vast majority of existing literature (see for instance Bhattacharya et al. (2017), Dong et al. (2017), Hu et al. (2018) and Zoundi (2017)) show that increasing the share of renewable energy in the energy mix acts as a primary measure to mitigate the environmental effects of CO_2 emission without compromising the sustainability of economic growth. However, despite the rapidly increasing share of RE sources, the domination of fossil fuels, such as oil, coal and gas, as primary sources of energy are not likely to be replaced in the near future. This is likely due to the inefficient allocation of global direct fossil fuel subsidies which in 2016 were estimated to be more than USD 360 billion, or twice as much as that of RE sources (REN21, 2018). Accordingly, new investments in RE sources become less economically attractive, particularly in many developing countries which still rely heavily on relatively cheaper yet less environmental friendly fossil fuels for promoting their economic development. However, Diesendorf and Elliston (2018) believe that the barrier for the deployment of RE sources is not solely due to either technical or economical, but it is also highly influenced by political, institutional and cultural aspects. As of 2016, modern RE sources (excluding traditional use of biomass) accounted for approximately 9 percent of the world's total final energy consumption (TFEC). By 2040, the contribution of modern RE sources in the energy mix is expected to reach at least 13 percent of TFEC under the Current Policies Scenario, or up to 28 percent of TFEC under the Sustainable Development Scenario (IEA, 2017).

In the light of the B2C target, a great number of literature have attempted to forecast the future level of CO_2 emissions which involves dynamic interactions between CO_2 emissions, energy consumption and economic growth (see for instance Böhmelt (2017), Ding et al. (2017), Hong et al. (2018), Köne and Büke (2010), Pérez-Suárez and López-

Menéndez (2015), and Vandyck et al. (2016)). However, Flint (2013) argues that a comprehensive assessment on sustainability needs to consider not only economic security and ecological integrity, which have been extensively discussed in those aforementioned studies, but also social equity of well-being which will ensure equal access to the productive base of economy for all people. Additionally, Arrow et al. (2012) argue that in the framework of sustainability, the equity of well-being should include both current well-being and potential well-being of future generation. Hence, the primary criterion for assessing the sustainability of economic development is whether or not the potential well-being of future generation can be maintained from being declining over time. The motivation of our paper is, therefore, to investigate to what extent do CO_2 emissions mitigation scenarios influence the sustainability of economic development. First, we forecast how the CO_2 emissions of nations will progress in the next two decades based on several different assumptions about the future development of per capita income, population density, energy consumption and the share of RE in energy mix. Furthermore, we analyze the impacts of those scenarios on sustainability by forecasting how the productive base of the economy changes over time. Our analysis relies on the machine learning approach which is known for its superior predictive performance compared to other parametric and semi-parametric models (Athey and Imbens, 2017; Mullainathan and Spiess, 2017).

4.2 Literature review

Well-being is a yardstick that measures the quality of good life which can be assessed from two different point of views, i.e. objective and subjective approach (Alatartseva and Barysheva, 2015; Qizilbash, 2009; Veenhoven, 2000; Western and Tomaszewski, 2016). The term well-being that we use in our paper refers to the objective approach which measures the quality of various dimensions of life indicators covering not only material resources, such as income and produced goods, but also social attributes, such as education and health (Western and Tomaszewski, 2016). In terms of sustainability, Hamilton and Hartwick (2014) and Mumford (2016), among others, argue that a sustainable development path is characterized by a non-declining value of well-being over time. Thus, assessment on sustainability requires quantitative measurement of current and future value of well-being. However, finding a single measure for properly measuring well-being is rather challenging (Mumford, 2016). Senik (2014) argues that wealth, instead of gross domestic product (GDP), is the most appropriate measure for well-being, although the positive correlation between wealth and well-being can only be observed at individual level.

In economics terms, well-being would be increasing when wealth is increasing. The wealth can be defined as the sum of capital assets that form the productive base of economy which is measured in physical units and valued in monetary units (Hamilton and Hartwick, 2014). The inclusive wealth (*IW*) framework provides a single measure of wealth which comprehensively measure the productive base of the economy covering three types of capital assets of nations namely: (i) produced capital, which covers all types of man-made infrastructure, such as roads, buildings, and machines; (ii) human capital, which covers population, health, knowledge and skill from education; and (iii) natural capital, which covers both renewable and non-renewable resources including forest resources, fisheries, agriculture land, fossil fuels and minerals (Arrow et al., 2012; Managi and Kumar, 2018; UNU-IHDP, 2012, 2015). The notion of sustainable well-being in the *IW* framework follows the weak sustainability perspective which allows substitutability between each type of capital asset as long as the total wealth can be maintained from being declining over time.

In addition to the productive base of the economy, assessment on sustainability needs to take into account externalities from environmental pollution. Hamilton and Hartwick (2014) and Senik (2014), among others, argue that environmental pollution, such as the excessive accumulation of anthropogenic CO_2 in the atmosphere, is also an integral part of wealth which contributes negatively towards well-being. Therefore, the total gain in aggregate wealth from converting natural capital into either produced capital or human capital needs to be adjusted by the economic loss due to carbon damages which arises as an inevitable side effect of the process. This notion of sustainability clearly suggests that higher level of well-being is likely to be achieved by reducing CO_2 emissions. However, it also suggests that policy aiming for zero CO_2 emission should be implemented cautiously due to the potential loss of well-being from restraining natural capital conversion. For these reasons, we prefer to use the adjusted *IW* (in this paper, we use *IW* and adjusted *IW* interchangeably) as a proxy of well-being since it provides a single measure of wealth which also takes into account exogenous adjustments from carbon damages, oil capital gains and total factor productivity.

Some previous studies have attempted to identify the primary drivers of CO_2 emissions in order to mitigate its adverse effect on the environment and well-being. The vast majority of the literature show that energy consumption and economic growth are the two main contributors of CO_2 emissions (see for instance Kaika and Zervas (2013) and Tiba and Omri (2017) for a literature survey on energy-income-emission relationship). For the case of energy consumption, there is unanimous agreement among the literature that energy consumption is inextricably linked to CO_2 emissions (see for instance Ahmed et al. (2017), Antonakakis et al. (2017), Zaman and Moemen (2017) and Zoundi (2017)). However, there is no general consensus about the impact of economic growth on CO_2 emissions. For instance, Antonakakis et al. (2017), Fernández-Amador et al. (2017) and Steckel et al. (2013) show that there is a monotonously increasing relationship between economic growth and CO_2 emissions. On the contrary, Pao and Tsai (2011), Apergis and Ozturk

(2015), Sugiawan and Managi (2016) and Zaman and Moemen (2017), among others argue that at a certain level of economy CO_2 emissions will be decoupled from economic growth, supporting the existence of EKC hypothesis. Additionally, some literature does reject the monotonicity of the income-CO_2 emission relationship, however they find that income-CO_2 emission relationship is best depicted either by an N-shaped or M-shaped curve (see, for example Ahmed et al. (2017), Pérez-Suárez and López-Menéndez (2015) and Yang et al. (2015). Having recognized the primary drivers of CO_2 emissions, different forecasting methods have been proposed to forecast the future level of CO_2 emissions by taking energy consumption and economic growth as independent variables. In addition to those variables, the share of RE sources and population growth have also been considered as influential predictors of future CO_2 emissions (see for example Apergis and Ozturk (2015) and Hong et al. (2018)).

The vast majority of the existing literature have mainly focused on either improving the accuracy of forecasting or analyzing different scenarios to reduce future CO_2 emissions. Several previous studies have also attempted to study the trade-off between CO_2 emissions and economic growth (see for instance Marjanović et al. (2016)). However, only a few studies have focused on assessing the impact of CO_2 emissions reduction on human well-being. For instance, Smith and Myers (2018) have investigated the impact of anthropogenic CO_2 emissions on global human nutrition and find that the increasing trend of CO_2 emissions poses a serious threat to malnutrition. Additionally, West et al. (2013) and Shindell et al. (2018) predict that CO_2 emissions mitigation scenario will be beneficial for global human health by preventing premature death worldwide. Nevertheless, well-being is not a straightforward concept that can be simply proxied by a single aspect, such as health dimension. Therefore, unlike previous studies, we use per capita *IW*, which comprehensively measures all dimensions of well-being, as our object of analysis. Sustainability criterion will be satisfied if CO_2 emissions reduction scenario does not lead to a declining per capita *IW*. In addition to the total wealth, we will also evaluate the impact of CO_2 emissions reduction scenario on disaggregated *IW* which includes produced, human and natural capital.

4.3 Forecasting future CO_2 emissions by machine learning method

To observe the impact of CO_2 emissions mitigation scenarios on sustainable well-being, we utilize the adjusted *IW* index of Inclusive Wealth Report 2018 (Managi and Kumar, 2018) as a proxy of well-being. In addition to per capita *IW*, which is measured in constant 2005 USD, we consider per capita CO_2 emissions and total CO_2 emissions as our dependent variable. Historical per capita of energy consumption (kilograms of oil equivalent), per capita GDP (constant 2010 US dollars), population density (people per square kilometer of land area) and the share of renewable energy (percentage) are taken as our predictors. Our analysis involves a balanced panel of 105 countries, from 1992 to 2014. To find the linkage among the variables, we use the following empirical relation:

$$CO2PC_{it} = f(CO2PC_{it-1}, EC_{it}, GDP_{it}, PD_{it}, RE_{it}) \quad (4.1)$$

$$CO2KT_{it} = f(CO2KT_{it-1}, EC_{it}, GDP_{it}, PD_{it}, RE_{it}) \quad (4.2)$$

$$IWPC_{it} = f(IWPC_{it-1}, EC_{it}, GDP_{it}, PD_{it}, RE_{it}) \quad (4.3)$$

Our analysis relies on the decision trees (DTs) model, one of non-parametric supervised machine learning methods which utilizes a tree structure, comprising of nodes, branches and leaves, to discover the structure of data (Lantz, 2013). The basic idea of DTs is to model the interaction between independent variables and outcome variable by creating partitions of data (nodes and branches) based on a set of rules which provides the most homogeneous responses (the lowest sums of squared error value) with respect to the outcome variable (leaves) (Elith et al., 2008; Miller et al., 2016). The tree structure is the primary and distinctive feature of DTs models which allows for an easier and more convenient interpretation of the models. Compared to other parametric and semi-parametric models, DTs also provide several key advantages which include the ability to model the nonlinearity between predictors and outcome variable, the ability to identify the interactions effect between predictors and the ability to deal with the problems with missing data. Furthermore, DTs models are also capable of measuring the relative importance of each predictor on outcome variable, which allows us to identify the most influential predictors of the outcome variable (Elith et al., 2008; Miller et al., 2016).

Despite the aforementioned advantages, DTs have a worth mentioning drawback in terms of low forecasting accuracy arising from its hierarchical structure. Nevertheless, the predictive performance of DTs can be significantly improved by using a meta-learning approach which is known as ensembles. The principal concept of an ensemble is to combine multiple weak learner DTs to form a group of strong learners having considerably higher predictive accuracy (Lantz, 2013). To date, there are two well-known approaches to create ensembles specifically bootstrap aggregation or bagging method (Breiman, 1996), such as in bagged trees and random forest (Breiman, 2001; Prasad et al., 2006), and boosting method (Freund and Schapire, 1997). Bagging method creates an ensemble by growing a set of DTs from bootstrap sampling the original training data. The value of the ensemble is then calculated by taking the average of all DTs in the ensemble (Breiman, 1996). This method improves model's accuracy by reducing variance and ignoring the presence of outliers. However, Elith et al. (2008) argue that such method is incapable of reducing model bias because each DTs is grown based on a bootstrap sample having the same distribution as the original training set. Boosting method overcomes this weakness by creating an ensemble through an iterative forward stagewise process of fitting multiple sets of DTs with a gradually increasing focus on observations that were poorly predicted by the previous set of DTs. Afterward, the final value of ensemble is taken from the linear combination of those sets of DTs. These will result in an ensemble that minimizes both bias and variance (Elith et al., 2008; Miller et al., 2016). We will utilize both bagging and boosting methods to improve the predictive performance of our models.

The predictive power of our models will be assessed by using three goodness-of-fit measures: mean absolute error (MAE), mean absolute percentage error (MAPE) and root mean square error (RMSE), which are expressed as follows:

$$\mathrm{MAE} = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n}|A_i - P_i|} \qquad (4.4)$$

$$\mathrm{MAPE} = \left(\frac{1}{n}\sum_{i=1}^{i=n}\frac{|A_i - P_i|}{A_i}\right) * 100 \qquad (4.5)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n}(A_i - P_i)^2} \quad (4.6)$$

where n is the number of observations in the data set while A_i and P_i are the actual observed data and the predicted values, respectively. Additionally, we will also evaluate the correlation between the predicted and actual values and the diversity of predicted values compared to the actual values in order to assess how well the predicted values correspond to the true values (Lantz, 2013). Our final model is the one that provides both the highest accuracy (which is indicated by the lowest value of MAE, MAPE and RMSE) and the closest diversity to the actual values (which is indicated by the highest correlation value and the smallest deviation in the spread of data).

4.4 The impact of CO_2 emissions mitigation scenarios on well-being

The primary objective of our paper is to analyze the impact of CO_2 emissions mitigation scenarios on sustainable well-being. To meet this objective, we take per capita CO_2 emissions, total CO_2 emissions and per capita total wealth (per capita *IW*) as our outcome or dependent variables, while per capita energy consumption, per capita GDP, population density and the share of renewable energy are taken as our predictors or independent variables. We begin our analysis by identifying the main drivers of CO_2 emissions and the primary determinants of well-being. This includes identifying predictors with nonlinear effects, detecting group of predictors that have non-additive effects and observing how these predictors affect some or all outcome variables. Therefore, it is necessary to simultaneously analyze the key structural features of our data by using a highly flexible and interpretable model building approach. For this purpose, we rely on DTs ensembles known as the multivariate boosting regression method which is available in *mvtboost* package (Miller et al., 2016). This method provides us with the relative influence of each predictor on outcome variables which is quantified and scaled so that the sum adds to 100%. This enables us to easily identify which predictors influence which outcome variables and which predictor has the largest influence on the model.

Figure 4.1 shows the relative influence of our predictors on all outcome variables. From Figure 4.1, we can see that per capita energy consumption significantly affects all outcome variables. For the case of per capita CO_2 emission, per capita energy consumption is largely dominating with a relative influence of almost 90%. However, the impact of per capita energy consumption on total CO_2 emission is somewhat modest with a relative influence less than 24%, while population density is found to be the most influential predictor for total CO_2 emission with a relative influence of more than 50%. Furthermore, together with the share of renewable energy, per capita energy consumption is also found as a significant predictor of per capita IW with a relative influence around 29%. In contrast to the results from correlation matrix, the impacts of per capita GDP on all outcome variables are rather small, except for per capita IW, which has a relative influence around 22%.

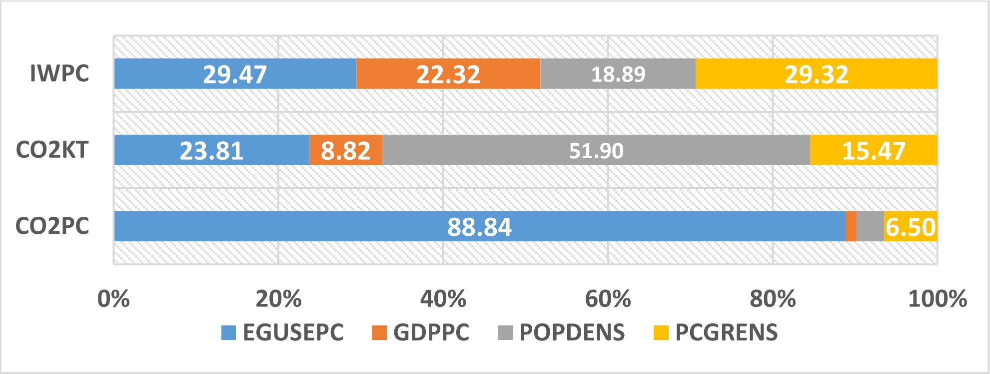

Figure 4.1 Relative influence of predictors on outcome variables

In order to comprehend the directions and functional form of the interactions, the interpretations of relative influence need to be complemented by a partial dependence plot, which draw the fitted values of the model against individual predictors (Miller et al., 2016). Such plot is also very useful for visually identifying nonlinear interactions between variables. Additionally, this plot can be extended further into a three-dimensional plot to account for the joint effects of two predictors. Figure 4.2 shows the three-dimensional partial dependence plots of three most influential predictors for each outcome variable. From Figure 4.2, we can see that in general there are nonlinear interactions between all predictors and all outcome variables, except for the case of per capita energy consumption and per capita CO_2 emissions, which to a certain extent can be approximated by a linear function. In terms of directions of the influence, we find a rather intriguing finding for per capita energy consumption, since it shows a positive impact on all outcome variables. This finding suggests a trade-off between boosting and restraining per capita energy consumption to achieve either a higher well-being or a better environment quality, respectively. Our finding is consistent with that of Antonakakis et al. (2017) who argue that higher economic growth and environmental sustainability is not likely to be achieved at the same time. From the plots, we can also observe the beneficial impacts of renewable energy on CO_2 emissions reduction for both per capita and total emissions.

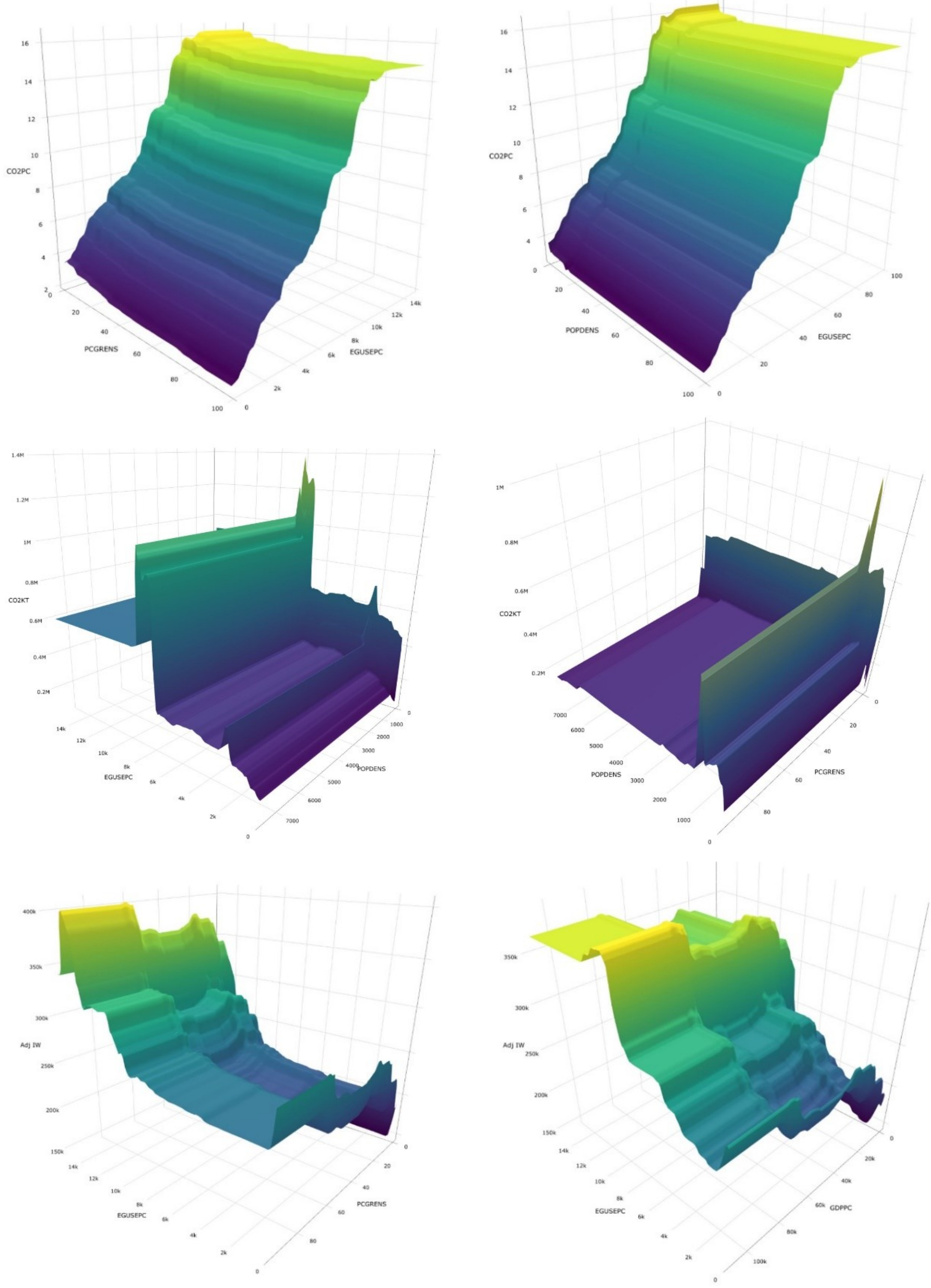

Figure 4.2 3D partial dependence plots of three most influential predictors

Similarly, the beneficial impacts of renewable energy are also found on per capita *IW* alongside per capita GDP. Our findings support the previous studies of Bhattacharya et al. (2017) and Cai et al. (2018), among others, who found beneficial impacts of renewable energy on both CO_2 emissions reduction and stimulating economic growth. Furthermore, despite its considerably strong influence, the impact of population density on increasing level of CO_2 emissions is only found on lower population density, while higher population density is found to have lower pressure on CO_2 emissions. This in line with the findings of Apergis and Ozturk (2015) who found a significant and nonlinear impact of population density on CO_2 emissions.

Having identified the main drivers of CO_2 emissions and the primary determinants of well-being, we carry on with forecasting the total CO_2 emissions over the next two decades. Our forecast relies on DTs ensembles which are improved by using both bagging and boosting method. Before commencing the forecast, we need to calibrate our model to ensure its accuracy and stability. For this purpose, we need to split our data into training and test set. The training set contains a global panel covering 1992-2010 period, while the test set covers a global panel from 2011 to 2014. The training data set is then calibrated by using *caret* package (Kuhn, 2008) with 5-fold cross-validation to minimize the in-sample forecasting error. Afterwards, we use the test set, which is treated as unobserved data, to assess the accuracy and stability of our model for out-of-sample forecast. For the final model specification, we choose the one that gives the smallest in-sample MAE, MAPE and RMSE. Additionally, we also need to consider the ability of our model to forecast extreme values by evaluating the distribution of the forecasted value by using five-number summary statistics (minimum value, 1st quartile, median, 3rd quartile and maximum value).

Table 4.1 provides the predictive performance of our CO_2 emissions model. From Table 4.1 we can see that both bagging (random forest) and boosting (gradient boosting) method demonstrate an excellent prediction performance with MAPE value less than 10 percent for both in-sample and out-of-sample forecast. However, from the five-number summary statistics we can see that both methods show narrower ranges of predicted values compared to the actual data. For in-sample forecast, both of our model are doing fairly well in predicting the values below the 3rd quartile, but the bagging method fails to accurately predict the extreme values. Nevertheless, the bagging method still provides a better MAPE value compared to the boosting method. In terms of out-of-sample predictive performance, the bagging method still outperforms the boosting method with a MAPE value of 0.081, which is slightly lower than the error from the boosting method. The bagging method also displays a good performance in forecasting the range of values below the 3rd quartile, which were falsely estimated by the boosting method. For these reasons, we prefer to choose bagging method as our final model for forecasting.

Table 4.1 Predictive performance of CO$_2$ emissions DTs model

Summary Statistics	**In-sample**			**Out-of-sample**		
	Actual	***Bagging***	***Boosting***	***Actual***	***Bagging***	***Boosting***
Minimum	576.0	720.0	889.0	2259.0	2104.0	-826.0
1st Quartile	6551.0	6570.0	6744.0	9428.0	9057.0	9948.0
Median	39673.0	40526.0	40617.0	44252.0	46809.0	45783.0
Mean	231858.0	231488.0	231859.0	308078.0	285548.0	294417.0
3rd Quartile	157923.0	159231.0	157864.0	202427.0	188418.0	189401.0
Maximum	8776040.0	7913604.0	8775718.0	10291927.0	7910549.0	8776668.0
Correlation	-	0.999	0.999	-	0.999	0.999
MAE	-	5183.20	2301.56	-	32804.96	23040.08
MAPE	-	0.061	0.075	-	0.081	0.096
RMSE	-	32016.02	3613.20	-	216348.80	133199.7
RMSPE	-	0.660	0.144	-	0.118	0.148

The next step is to extend our forecast for the CO$_2$ emissions until 2040 by using the obtained random forest model. We use the scenarios from Global Energy Assessment (GEA) (IIASA, 2012) to obtain the projections of the world’s per capita energy consumption in the next two decades. The GEA’s scenarios contain three extremely different pathways to model the changes in structures of the future energy systems: (i) efficiency pathways, which are characterized by rapidly increasing share of renewable energy and increasing efficiency in energy intensive sectors, such as transportation, buildings and industrial sector; (ii) supply pathway, which are characterized by considerable scale up in the supply side with a smaller share of renewable energy in the energy mix; and (iii) mix pathways, which use intermediary assumptions between the two scenarios (IIASA, 2012). The aforementioned pathways of the GEA's scenarios were made without considering the possibility of any changes in the future socioeconomic aspect. In order to take into account these changes in our model, we employ the GEA's scenarios to predict future per capita GDP and we use the world population prospect of the United Nations to obtain the projected global population growth until 2040. Furthermore, by using similar method and predictors, we also forecast the change in per capita *IW* to assess the impacts of energy consumption pathways on sustainable well-being.

From Figure 4.3, we can see that levels of CO_2 emissions in 2040 are projected to increase by approximately 34.94%, 25.56% and 15.12% above the level of 2014 emissions for the case of supply, mix and efficiency scenario, respectively. Our results slightly deviate from that of the World Energy Outlook 2017 (IEA, 2017) which forecasted an increase by 33.17% for the Current Policies Scenario and 11.26% for the New Policies Scenario. In terms of CO_2 emissions mitigation strategy, our forecasts show that none of the scenarios is associated with a decreasing trend of CO_2 emissions. Even if we refer to the efficiency scenario, we find no evidence that CO_2 emissions will be peaked, implying that the B2C target is rather difficult to be achieved. Next, we aim to analyze further whether variations in CO_2 emissions patterns are related to the structure of the economy. For this purpose, we divide our sample into three groups according to their income level: low and lower middle income, upper middle income and high income. From Figure 4.3, we can see significant contributions from low and lower middle income countries toward the increasing trend of CO_2 emissions, ranging between 2.04 and 3.28 times higher than the 2014 level. The increasing trend of CO_2 emissions is also attributable to upper middle income group, which at the end of our study period is projected to increase, at a slower rate compared to that of low and lower middle income countries, by up to 30% of the 2014 level. On the other hand, we expect to see a declining trend of CO_2

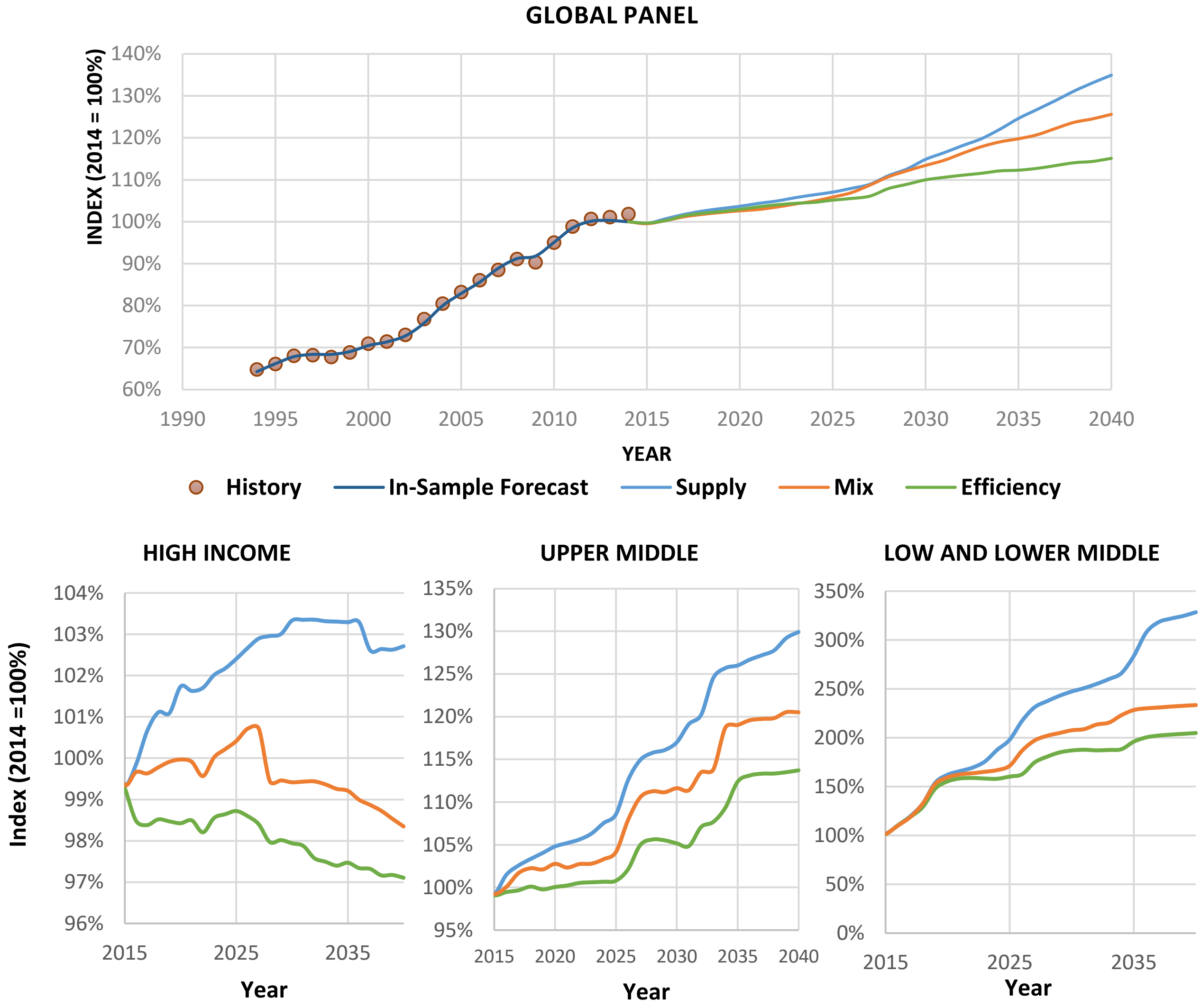

Figure 4.3 Projections of CO_2 emissions

emission for high income group for mix and efficiency scenarios. Moreover, although the supply scenario initially projects an increasing trend of CO_2 emission for high income group, it is expected to reach its peak around 2035.

These results are not beyond expectation since investments in low-carbon climate resilient infrastructures are very costly and might not be affordable for developing countries. The World Energy Outlook 2017 (IEA, 2017) estimates the required investment for clean energy technologies and energy efficiency that will cost around USD 60 trillion in the New Policies Scenario and up to USD 69 trillion in the Sustainable Development Scenario. These findings support the well-known argument of Beckerman (1992) who claimed that the most feasible way to deal with environmental problems is to become rich, which later on becomes the fundamental idea of the EKC hypothesis. Furthermore, our findings suggest that CO_2 emissions mitigation strategies require not only a strong long-term commitment from policymakers, but also significant public behavioral and attitudinal changes. Flint (2013) argues that most of sustainability problems can be effectively solved by encouraging intensive community engagement because there are a lot of socioeconomic and environmental interactions that are outside the reach of conventional regulations.

In terms of the productive base of the economy, we can see from Figure 4.4 that all of the pathways lead to increasing global average per capita *IW*, suggesting a quite promising sustainable future. The highest gain in per capita *IW* is projected by mix scenario which in the end of our study period is expected to contribute for approximately 4.58% increase in per capita *IW* with respect to the 2014 level. This is followed by supply and efficiency scenario with a contribution of approximately 4.57% and 4.28%, respectively. However, from Figure 4.4 we can see also see that in medium term the impact of efficiency scenario on wealth gain is noticeably higher than the two other scenarios. Our findings suggest a diminishing beneficial impact of energy efficiency pathways on per capita wealth gain in the long term. Switching from global analysis, we find noticeably different patterns of wealth gain between country groups. For high income economies, we expect to see a steady increase in average per capita wealth of which efficiency scenario is projected to create higher wealth gain compared to mix and supply scenarios. Hence CO_2 emissions mitigation policies, can be implemented without any potential adverse effects to future well-being. However, we find contradictory patterns for both upper middle income and low and lower middle income groups where supply scenario is expected to provide the highest gain in per capita wealth. As a result, mitigation scenarios aiming to significantly reduce the level of CO_2 emissions might lead to a potential loss in projected well-being for up to 1%.

We proceed our analysis further to investigate the impacts of CO_2 emissions reduction scenarios on disaggregated *IW* which includes natural, produced and human capital. From Figure 4.5, we can see that in general we expect to see a steady increasing average values of both human and produced capital. However, these are followed by serial depletion of natural capital, which to some extent is undesirable for sustainability. We also find compelling evidence of potential trade-off between capital assets which is attributable to each of the energy pathways. For instance, while it is favorable for improving produced and human capital, opting for supply scenario leads to a higher depletion rate of natural capital. On the other hand, opting for mix scenario might result in preservation of natural capital, but it might also cause a potential loss in produced capital. In the light of sustainable well-being, the weak concept of sustainability suggests that the potential loss in natural capital at its allowable degradation rate is acceptable as long as it is sufficiently compensated by the increasing social values of other types of capital assets (Islam et al., 2018). Hence all of the energy pathways might be associated with sustainable well-being given that the total *IW* can be maintained over time by ensuring that the potential loss in natural capital is substituted by

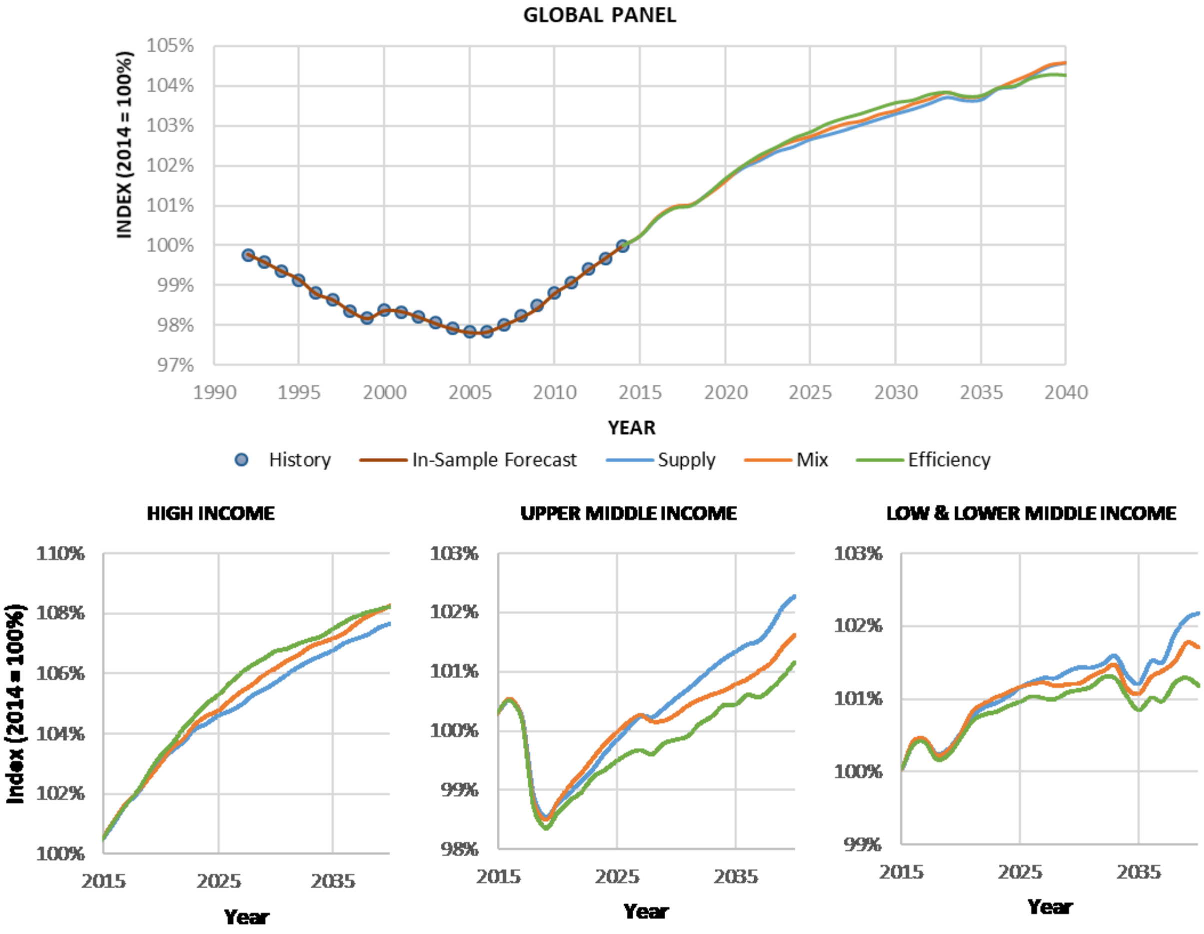

Figure 4.4 Projections of average per capita *IW*

sufficient gain in either human or produced capital, and vice versa. Furthermore, we identify different impacts of the energy scenarios on each income groups. For instance, efficiency scenario is associated with higher gain in human capital for both high and upper middle income groups. However, for the case of low and lower middle income group, the highest gain is linked to supply scenario. Additionally, unlike other groups, high income group is likely to receive additional benefits to natural capital from efficiency scenarios. Therefore, opting for efficiency scenario is likely to give the highest socioeconomic benefits for high income countries since it provides both highest CO_2 emissions reduction and highest gain in potential well-being. However, for the case of upper middle and low and lower middle income groups, the circumstances are somewhat complicated since highest CO_2 emissions reduction is associated with lowest potential gain in well-being.

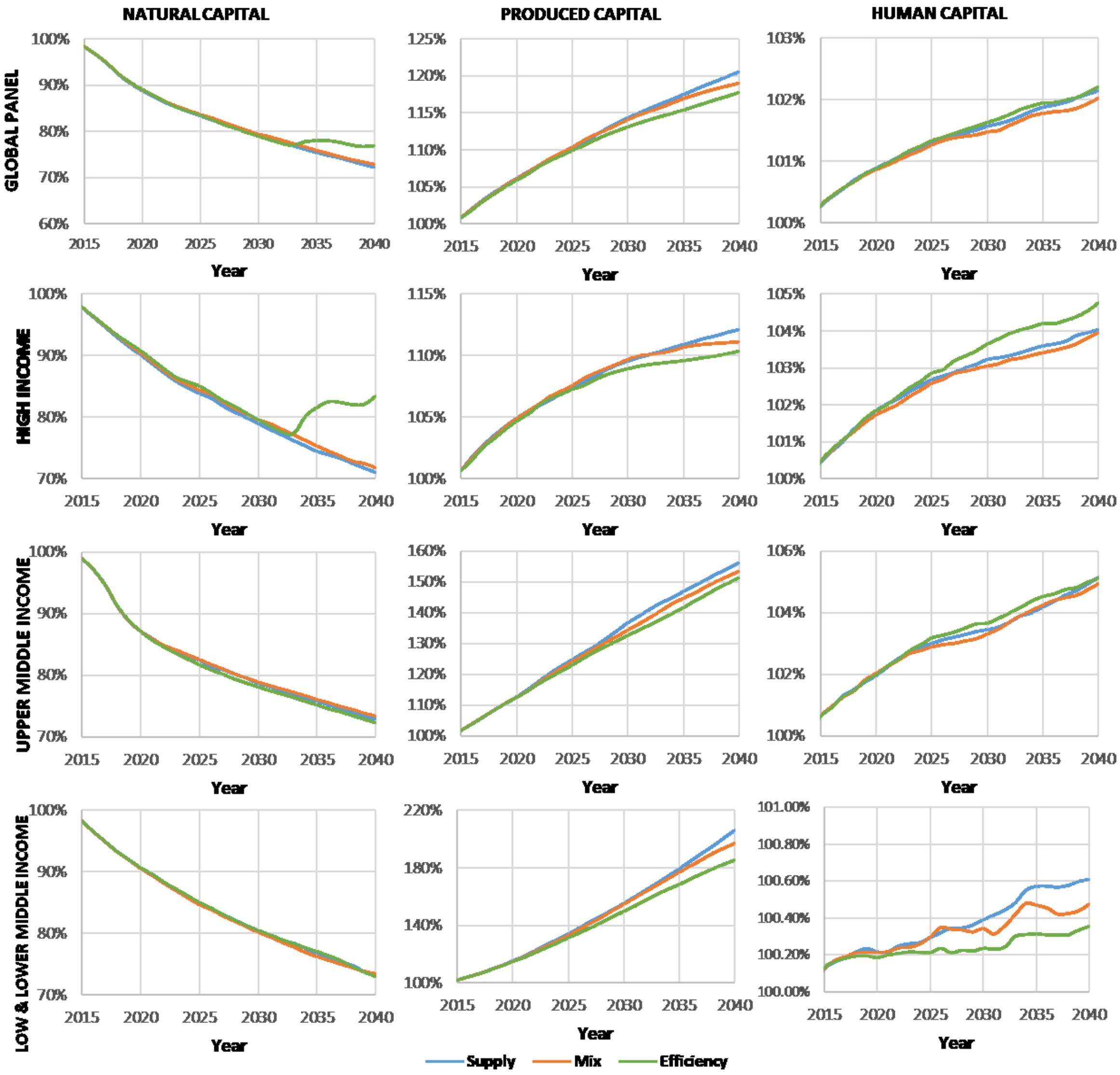

Figure 4.5 Projection of disaggregate changes in per capita *IW*

4.5 Conclusions and policy implications

This is the first study relating future scenarios of economy to the wealth, not GDP, in terms of climate change analysis. The objective of this study was to investigate the impact of CO_2 emissions mitigation scenarios on sustainable well-being. We used the inclusive wealth (*IW*) as the proxy of well-being and employed the decision trees (DTs) model, a non-parametric supervised machine learning method, to forecast the growth of well-being over the next two decades based on three different energy pathways. We found evidence of a promising sustainable future for all energy pathways which was indicated by a steady increasing average per capita *IW*. The highest gain in average per capita *IW* was associated with mix scenario, while efficiency scenario led to the lowest growth in CO_2 emissions. However, the impacts of those energy pathways on well-being in the medium term differed significantly from the long term. The growth patterns of average per capita *IW* also differed widely between income groups of which high income group has a greater tendency to follow the sustainable development path.

Although suggesting new policies is beyond the scope of this paper, our findings highlight some important policy implications. First, our models suggest that CO_2 emissions mitigation scenarios can be implemented with no adverse effects on the sustainability of well-being. However, these policies should be carried out with caution by considering the structure of the economy and the possible impacts of the policies in both medium and long run. Second, our findings emphasize the necessity to complement the CO_2 emissions mitigation scenarios with the institution of better natural resources management systems, particularly in developing economies, in order to obtain supplementary added value from natural capital to total wealth gain, which in our study was found only for high income group.

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Chapter 5 The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy

5.1 Introduction

The quest for higher economic growth cannot be detached from the issue of energy security and environmental deterioration. On the one hand, serves as an essential input for economic activity, but on the other hand, extensive use of energy exerts greater pressure on the environment, either due to by-product pollutants or depletion of natural resources. In the context of sustainability, economic development should be achieved while making efforts to preserve the environment so that its utility for future generations is maintained. The environmental Kuznets curve (EKC) hypothesizes that instead of being harmful to the environment, economic development is favorable for improving environmental indicators that will eventually lead to a sustainable development path. The EKC hypothesis posits that the relationship between economic growth and environmental degradation follows an inverted U-shaped curve. It suggests that after exceeding a certain level of gross domestic product (GDP) per capita, the increasing trend of environmental degradation reverses so that higher GDP per capita leads to environmental recovery that reverses the environmental damage incurred at the initial stages of economic development.

The strong links between economic development, energy consumption, and environmental quality render the empirical evidence of the EKC hypothesis largely significant, particularly for a developing country such as Indonesia, which is currently striving to boost its economy. Over the last decade, Indonesia’s economy grew rapidly at an annual average rate of 5.4 percent per year. This was followed by an increasing amount of total energy supply to approximately 1,525 million barrel of oil equivalents (BOE) in 2013 from 1,111 million BOE in 2000, with an annual average growth rate of 2.5 percent. Accordingly, the total emissions of carbon dioxide (CO_2) from fossil fuel combustion also showed an upward trend with a slightly faster average growth rate of 3.9 percent per year, amounting to 424.6 million tons CO_2-equivalent in 2013 from 258.3 million tons CO_2-equivalent in 2000. More than 38 percent of that combustion resulted from electricity generation (IEA, 2015). This has created serious environmental problems, including the threat of climate change. A series of energy- and environment-related policies have been introduced by the Government of Indonesia (GoI) as countermeasures to mitigate the environmental impacts of greenhouse gas (GHG) emissions. Therefore, the empirical evidence of the EKC will depict the efficacy of those policies in promoting green growth and harnessing a sustainable development path.

Numerous studies have been carried out to investigate the existence of the EKC hypothesis with respect to CO_2, both for developed and developing countries. However, most of them rely on cross-country panel data analysis, portraying only general inferences of the EKC hypothesis that tend to disregard both the distinctive complexity of economic environments and the historical experience of individual countries (Ang, 2008; Lindmark, 2002; Stern et al., 1996). These studies underline the need for a country-specific CO_2 EKC study that provides the in-depth analysis that is required for framing effective energy and environmental policies for each country. Therefore, this paper aims to find empirical evidence of the EKC hypothesis for CO_2 in the context of Indonesia by examining the relationship between economic growth and environmental degradation using the Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran et al. (2001). Additionally, the high correlation between economic development, energy consumption, and environmental quality encourage us to study the EKC within this framework. Therefore, we also seek to study the potential of renewable energy sources in improving environmental quality and initiating the EKC pattern.

5.2 The concept of the EKC hypothesis

Although technological progress has led to new discoveries that prevent the exhaustion of nonrenewable resources, environmental issues remain a major problem (Kaika and Zervas, 2013a). This has caused a marked shift in global development issues, from limit to growth, which primarily focused on the scarcity of natural resources, to sustainable development issues, which are concerned about the environmental impact of economic development (Ekins, 1993). In the early 1990s, the concept of the EKC hypothesis has emerged as a promising theory that will lead to sustainability. It began with the study of Grossman and Krueger (1991) finding an inverted U-shaped relationship between pollutants and income per capita. The fundamental idea of the EKC can be found later in the study of Beckerman (1992), who claims that environmental problems are strongly associated with poverty and that the most feasible way to address them is to become rich. Panayotou (1993) argues that environmental degradation occurring in the initial stage of economic development is, without a doubt, inevitable. However, after reaching a certain level of income, further economic development will ameliorate the damage and eventually lead to improved environmental indicators. He also introduced the term EKC for the first time to differentiate this hypothesis from the famous Simon Kuznets hypothesis about the inverted U-shaped relationship between income inequality and economic development. These studies have laid noteworthy foundations for the development of the EKC hypothesis, which was followed by subsequent influential studies such as Grossman and Krueger (1994), Selden and Song (1994), List and Gallet (1999) and Dinda (2004).

The rationale of the EKC hypothesis is comprehensively explained by Grossman and Krueger (1991). They differentiate the impacts of economic growth on environmental quality into three effects: scale effect, composition effect, and technique effect. At the initial stage of development, the increasing level of pollution is inevitable because of the acceleration of economic development and the extensive extraction of natural resources that exceed those resources' regeneration rates (Panayotou, 1993). This process is marked by a structural change in the economy from agricultural to industrial. At this stage, economic growth undergoes a scale effect that has negative impacts on the environment and is responsible for the upward trend of the EKC. However, after reaching a certain level of income, this trend might reverse. As income increase, the economy undergoes a structural transformation from a resource-intensive economy to a service- and knowledge-based, technology-intensive economy (Dinda, 2004). This stage is referred to as the composition effect, leading to development of cleaner industries and having positive impacts on the environment. Finally, economic growth also has positive impacts on the environment through the technique effect. A significant improvement in environmental quality is achieved from technological progress and the adoption of new technologies that tend to be both cleaner and more efficient (Dinda, 2004). However, this process requires adequate R&D investments, which become affordable after a certain economic stage (Kaika and Zervas, 2013a). The combination of these three effects, which correspond to various stages of economic development, might result in an inverted U-shaped relationship between economic growth and environmental quality. The positive impact of the composition and technique effects on the environment will compensate for the damages caused by scale effect, resulting in a downward EKC trend (Dinda, 2004).

Panayotou (1993) argues that the EKC pattern is not solely determined by advancement in technology; it is also induced by the increasing degree of environmental awareness and a higher share of environmental protection expenditures. He believes that as income grows, people's willingness to pay for environmental abatement will also increase, along with their growing awareness of the need to improve environmental quality. Kumar et al. (2012) and Managi and Okimoto

(2013) find that people’s attitude toward the environment can also be influenced by incidental events such as a surge in oil prices. They show a positive relationship between oil prices and clean energy firms’ stock prices, suggesting that consumer preferences for clean energy and technology increase as oil prices increase. Additionally, Panayotou (1993) argues that higher income leads to more stringent environmental regulations, which are essential for improving environmental quality. Dasgupta et al. (2001) supports his argument by showing a positive correlation between per-capita income and the stringency of environmental regulations. Similarly, Yin et al. (2015) show the significant role of environmental regulation in initiating EKC patterns.

The EKC hypothesis is an enticing view that suggests the existence of a turning point, subsequent to which the environmental benefits of economic growth will be achieved. Thus, based on this hypothesis, economic growth will improve both living standards and environmental quality, eventually leading to sustainability. However, this hypothesis has limitations that are worth mentioning. First, the estimated turning point of the EKC might occur at a very high level of income. As a result, for some countries, the positive effects of economic growth on environmental quality are impossible to achieve (List and Gallet, 1999). EKC opponents further argue that this turning point may go even higher because industrial societies continuously create new pollutants that will prevent the curve from declining (Dasgupta et al., 2002). In contrast, EKC proponents are optimistic that the turning point is actually shifting to the left, resulting in a more reasonable turning point. They suggest that the level of pollution starts to decline earlier, at a lower income level, along with economic growth (Dasgupta et al., 2002). Second, the EKC hypothesis does not apply to all types of pollutants, which have varied environmental impacts. The EKC patterns are more likely to be observable for pollutants that have both a local impact on the environment and a perceptible impact in the short term (Dinda, 2004; Kaika and Zervas, 2013b; Stern, 2004; Tsurumi and Managi, 2010a). For instance, air and water quality has been found to have EKC patterns with varying turning points for different types of pollutants (Grossman and Krueger, 1994). Similarly, Selden and Song (1994) find an inverted U-shaped relationship between air pollution and economic development. Specifically, the evidence for the EKC hypothesis can also be found for air pollutants, such as SO_2 and NO_x (Kumar and Managi, 2010; List and Gallet, 1999), and pesticide use (Managi, 2006). Nevertheless, in the case of global pollutants such as CO_2, which is considered the major GHG emission that cause global climate change, the result remains inconclusive.

In most cases, the EKC pattern for CO_2 emissions is rarely observed (for a summary of previous empirical studies of the CO_2 EKC, see, for instance, Kaika and Zervas (2013a)). This is likely attributable to the high correlation between energy consumption, economic growth and CO_2 emissions. Higher economic growth requires higher energy consumption, leading to higher CO_2 emissions (Ang, 2007; Apergis et al., 2010). Furthermore, Sun (1999) argues that the CO_2 EKC does not reflect a turning point at which environmental quality will start to improve, but it is just showing the peak of energy intensity. Thus, the EKC pattern for CO_2 emissions can only be found in countries that have reached peak energy intensity. Additionally, Tsurumi and Managi (2010b) show that the reduction of CO_2 emissions intensity can only be achieved through a structural change in CO_2 emissions, i.e., reducing the share of coal in energy production. This implies that emissions reduction requires more than just a higher income level for improving environmental quality and initiating the EKC pattern for CO_2 emissions.

Two well-known approaches have been widely used for investigating the EKC. The first relies on cross-country panel data analysis (see, for instance Arouri et al. (2012), Jaunky (2011), Narayan and Narayan (2010), Narayan et al. (2016), Richmond and Kaufmann (2006), Tsurumi and Managi (2010a) and Yang et al. (2015)), whereas the other one relies on a single region time-series analysis (see, for instance Al-Mulali et al. (2015), Bölük and Mert (2015), Iwata et al. (2010), Saboori and Sulaiman (2013), Saboori et al. (2012a), Saboori et al. (2012b) and Tutulmaz (2015)). In addition to the aforementioned methods, Halkos and Tsionas (2001) propose a cross-sectional data analysis by using the Markov chain Monte Carlo (MCMC) method to empirically find the existence of EKC by using switching regime models. However, this analysis is less preferable because it does not capture the dynamics of the income – environment relationship over a period of time. Cross-country panel data analysis indeed offers a more robust econometrical analysis. However, it portrays only the general inference of the EKC hypothesis, which might not be applicable to a specific region or country. For instance, Jaunky (2011) finds a positive correlation between income and CO_2 emissions both in the short and in the long run for panel of 36 high-income countries from 1980 to 2005, but based on a country-specific analysis, he provides evidence of an EKC only for 5 countries, including Greece, Malta, Oman, Portugal and the United Kingdom. Thus, to frame an effective energy- and environmental-related policy for a specific country, a time-series analysis approach is preferable. Such an analysis provides an in-depth examination based on the complexity of the economic environments and historical experiences of each country (Ang, 2008; Lindmark, 2002; Stern et al., 1996). However, it requires a reliable dataset for a relatively long time period, which might be difficult to obtain, particularly for developing countries.

From an empirical perspective, most of the EKC literature (see, for instance Al-Mulali et al. (2015), Bölük and Mert (2015), Iwata et al. (2010), Saboori and Sulaiman (2013), Saboori et al. (2012a), Saboori et al. (2012b) and Tutulmaz (2015)) tests the validity of the EKC hypothesis by employing squared or cubic functional forms of income—environmental quality models to estimate the range of possible turning points of the EKC in the economy, beyond which the environmental benefits of economic growth are likely to be achieved. Some of the estimated turning points are implausible because they lie outside the sample and cannot be achieved. Bernard et al. (2015) further suggest a parametric inference method that corrects for potential weak-identification of the turning point. However, Narayan and Narayan (2010) argue that such models are prone to problems of collinearity or multicollinearity because the models contain both income and square of income as exogenous variables. To avoid these problems, they suggest an alternative approach to evaluate the environmental impacts of economic growth by comparing the short- and long-run income elasticities of a linear model of income—environmental quality. They argue that the benefits of economic growth for mitigating CO_2 emissions will be achieved if long-run income elasticity is smaller than short-run income elasticity. Furthermore, Jaunky (2011) and Al-Mulali et al. (2015) argue that lower long-run income elasticity is not a strong indication of the EKC. However, an EKC-type relationship appears if the long-run income elasticity is negative, indicating that higher economic growth leads to improved environmental quality.

This paper's first objective is to find empirical evidence of the EKC hypothesis for CO_2 with specific reference to Indonesia by employing the Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran et al. (2001). There are several compelling reasons for choosing Indonesia as the subject of our research. With one of the largest economies in Asia, Indonesia has experienced outstanding economic growth, followed by a significant increase in energy consumption and CO_2 emissions from fossil fuel combustion over the past decade. Additionally, despite its huge potential for renewable energy, Indonesia's energy mix remains dominated by fossil fuels. Therefore, our second objective is to study the role of renewable energy sources in improving environmental quality and initiating the EKC pattern. To the best of our knowledge, only a few empirical studies have focused on analyzing CO_2 EKC specifically for Indonesia, and none of them have examined the potential of renewable energy sources within the EKC framework. One such study is conducted by Saboori et al. (2012b), who analyze the CO_2 EKC for Indonesia from 1971-2007 by incorporating foreign trade and energy consumption. They find a U-shaped relationship between income and environmental degradation, denying the existence of the EKC hypothesis. However, their findings might be misleading because they are using the critical values (CVs) reported in Pesaran et al. (2001), which according to Narayan (2005), are not applicable for small sample size. To accommodate the relatively small sample size in this study (40 observations), we use the CVs reported in Narayan (2005) for testing the cointegration between variables.

5.3 Indonesia's energy profile

Energy is an essential input for economic and social development. However, Indonesia's energy sector faces challenges in the context of sustainable development. First, despite its huge renewable-energy potential, Indonesia's energy sector is heavily dependent on fossil fuels. In 2014, Indonesia's total consumption of fossil fuels amounted to 1,358 million BOE, accounting for approximately 96 percent of total primary energy consumption (NEC, 2015). From Figure 5.1, we can see that oil was the main contributor of Indonesia's energy mix by 48 percent, followed by coal and gas. Regardless of its dominance over other energy sources, the share of oil in the national energy mix shows a decreasing trend. With an average growth rate of 9.9 percent per year, coal has managed to gradually reduce the share of oil in the national energy mix, which has grown at a slower average rate of 1.9 percent per year in the past decade (BPPT, 2014). Similarly, a high dependency on fossil fuels is found in the electricity sector. In 2014, total electricity generation was approximately 288 TWh, 88 percent of which was generated from fossil fuels, with coal accounting for approximately 52.8 percent of the total figure (Figure 5.2) (NEC, 2015). To increase the electrification rate to 100 percent by 2020 and to ensure the security of the energy supply, which is required for supporting economic development, the GoI has launched the Electricity Fast Track program to boost the electricity generation capacity. Under that program, the GoI is accelerating the construction of new power plants with a total capacity of 20 GW. Whereas the first phase of the program relies completely on coal-fired power plant, the second phase of the program encourages the use of renewable energy for electricity generation (BPPT, 2014; NEC, 2015). Upon completion of the first phase of the program, the share of coal in the national energy mix is expected to increase further. Second, Indonesia's energy sector is highly subsidized to ensure the availability and accessibility of energy for all levels of the community. In 2014, the government allocated more than 25 billion USD for energy subsidies, approximately 26 percent of which was allotted for electricity (NEC, 2015). This high subsidy level has imposed a great financial burden for Indonesia's state budget (APBN). Additionally, it has caused inefficient consumption of energy and discouraged the development of new and renewable energy (NRE) (NEC, 2014). Third, Indonesia is currently experiencing a wide range of environmental problems including threats of climate change that are likely caused by rapid economic growth and the extensive use of natural resources, particularly fossil-fuel combustion. The World Bank predicted that the economic loss attributed to climate change in Indonesia is estimated to reach 2.5-7.0 percent of GDP by 2100. Meanwhile, the health impact of air pollution can cost more than $400 million per year (Leitmann, 2009).

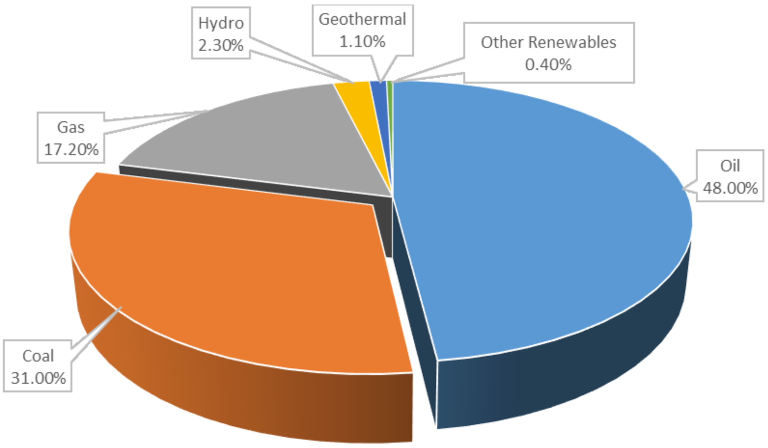


Figure 5.1 Indonesia’s primary energy mix 2014

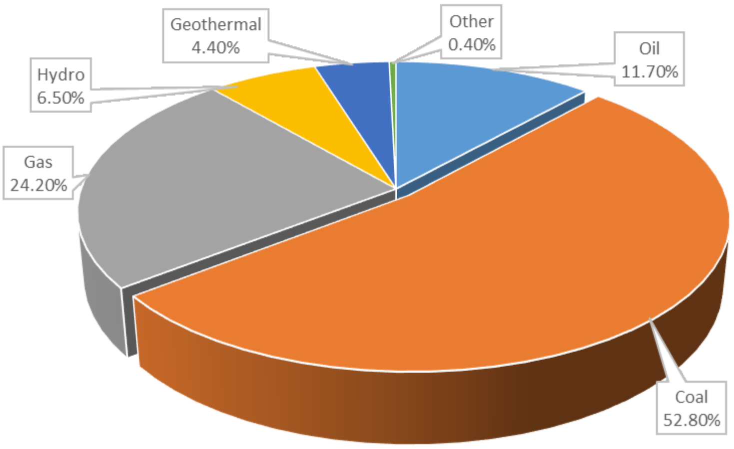


Figure 5.2 Indonesia’s electricity generation mix 2014

Indonesia has huge potential for renewable energy, including geothermal, hydropower, biomass, wind, and solar. However, it is unlikely that renewable energy alone will displace the major contribution of fossil fuels in the national energy mix in the near future because their utilization remains far beyond their maximum capacity because of either technical or economic constraints. With a total estimated technical potential of more than 273 GW (excluding the potential of ocean energy), only approximately 4 percent of renewable energy technologies have been utilized. Hydropower is the highest potential source of renewable energy with an estimated capacity of 75 GW, but it is currently underutilized because it has a total installed capacity of only 11 percent of its total potential, amounting to some 8,111 MW (NEC, 2015). With an estimated potential capacity of approximately 32 GW, biomass has become the second-largest renewable energy resource available, only approximately 5 percent of which has been utilized for electricity generation (NEC, 2015). Due to its geographical position on the equator and located in the ring of fire, Indonesia is blessed with an enormous potential for geothermal and solar energy. The potential of geothermal energy is estimated to be more than 28 GW, accounting for 40 percent of the world's potential geothermal resource (Hasan et al., 2012), less than 5 percent of which has been utilized (NEC, 2015). Additionally, notwithstanding its geographical advantages as an equatorial country, Indonesia's utilization of solar energy in Indonesia is relatively small. With an average solar radiation of 4.8 kWh/m^2/day, only approximately 71 MW of solar energy systems have been installed (NEC, 2015). In contrast, the potential for wind energy in Indonesia is rather low, with low wind speeds ranging from 3-6 m/s (NEC, 2015).

The GoI's commitment to mitigating climate change is stipulated in Presidential Regulation 61/2011 regarding the National Action Plan for GHG Emission Reduction. By 2020, GHG emissions are expected to be reduced by at least 26 percent, through Indonesia's own effort, or by at least 41 percent, with international support. This is followed by amending the national energy policy, which is regulated in Government Regulation 79/2014, to endorse the diversification of energy sources and gradually reduce Indonesia's high dependency on fossil fuels by developing NRE technologies that are economically competitive. By 2025, the share of NRE is expected to reach at least 23 percent of the total energy mix. This is expected to make a contribution of approximately 50 percent of total GHG emission reduction in 2035 (BPPT, 2014). Additionally, a series of feed-in tariff policies have been introduced to support the development of NRE, including geothermal and hydropower. The GoI has also attempted to increase efficiency in the energy sector by gradually reducing the amount of its energy subsidy and reallocating funds to make new investments in energy infrastructure.

5.4 Methodology

5.4.1 Econometric model and data

This paper uses a reduced-form model as a baseline estimation model to test the validity of the EKC hypothesis. This model allows us to measure the direct and indirect relationship between income and environmental quality without being distracted by additional variables that would distort this study's primary objective and lessen its degree of analytical freedom (see List and Gallet (1999)). We also seek to study the potential of renewable energy sources in improving environmental quality and initiating the EKC pattern. Renewable energy sources are a foreseeable vehicle for reducing high dependency on fossil fuels while mitigating the environmental effects of GHG emissions from fossil fuel combustion. Thus, the share of renewable energy sources acts as a proxy for composition effect that captures the structural change in energy production toward a less polluting technology. Our baseline estimation model can be written as follows:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln {Y_t}^2 + \gamma \ln ER_t + u_t \qquad (5.1)$$

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \gamma \ln ER_t + u_t \qquad (5.2)$$

where C is per capita CO_2 emissions; Y is per capita GDP; ER is per capita electricity production from renewable sources; and u is the standard error term.

Equation (1) is the conventional model for estimating the EKC, employing both income and square of income as exogenous variables. This model provides us with several possible functional forms of income – environmental quality relationships. When $\beta_1 = \beta_2 = 0$, this indicates a level relationship, implying no relationship between income and environmental quality. A linear relationship occurs if $\beta_2 = 0$ and $\beta_1 > 0$ for a monotonically increasing relationship or $\beta_1 < 0$ for a monotonically decreasing relationship. A quadratic relationship exists if $\beta_2 < 0$ for an inverted U (EKC) relationship, or $\beta_2 > 0$ for a U-shaped relationship. A turning point on the EKC at which economic growth is harmless for the environment exists if there is an inverted U-shaped relationship between income and environmental quality. Equation (2), however, is the alternative approach to evaluate the EKC relationships, as suggested by Narayan and Narayan (2010). In this model, the EKC relationship is evaluated by comparing the short- and long-run income elasticities. The benefits of economic growth for mitigating CO_2 emissions will be achieved if long-run income elasticity is smaller than short-run income elasticity. Additionally, the expected sign of γ is negative because renewable energy sources produce less CO_2 emissions than fossil fuels.

To avoid omitted variable bias, Equations (1) and (2) need to be expanded to include variables that capture scale effect and technique effect, and this paper uses the level of energy consumption and total factor productivity (TFP), respectively. Advancement in economy requires more energy as the main input in production. Consequently, a higher level of emissions will be generated as by-product of the process. Thus, energy consumption demonstrates the scale effect that has a negative impact on the environment. However, technical effect, which is indicated by technological progress and the adoption of new technologies, creates a positive impact on environment, either by increasing productivity and efficiency in production, or by reducing emissions per unit output (Stern, 2004). This paper uses TFP as a proxy for technical effect.

Annual data covering the period 1971-2010 are used in this study. CO_2 emissions (C) is measured in metric tons per capita. Per capita real GDP (Y) is in constant 2005 US dollars. Electricity production from renewable sources (ER) is measured in kWh per capita. Energy consumption is measured in kg of oil equivalent per capita. The abovementioned data are obtained from the World Bank, World Development Indicators 2015. In addition, we use the data on TFP, which are obtained from the Penn World Table (Feenstra et al., 2015).

5.4.2 ARDL bounds testing of cointegration

This paper utilizes the ARDL-bounds testing approach to cointegration developed by Pesaran et al. (2001) to examine the long-run relationship between income and environmental quality. This method has several advantages over other methods. First, the ARDL approach effectively corrects for the possible endogeneity of explanatory variables, thus providing unbiased estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous. Second, the ARDL test is suitable even if the sample size is small, such as in our study, which uses 40 observations. Third, the ARDL method does not require all of the variables to be integrated in the same order. Therefore, it can be applied regardless of whether the underlying regressors are integrated in order one (*I(1)*), in order zero (*I(0)*) or fractionally. As a result, we can avoid the uncertainties created by unit root testing. Finally, this method can simultaneously estimate causal relationships both in the short-run and in the long-run.

The ARDL approach to cointegration estimates the following unrestricted error-correction (UREC) model:

$$\begin{aligned}\Delta \ln C_t = \beta_0 &+ \sum_{i=1}^{p} \beta_{1i}\, \Delta \ln C_{t-i} + \sum_{i=0}^{q} \beta_{2i}\, \Delta \ln Y_{t-i} + \sum_{i=0}^{r} \beta_{3i}\, \Delta \ln (Y_{t-1})^2 + \sum_{i=0}^{s} \alpha_{4i}\, \Delta \ln ER_{t-i} \\ &+ + \lambda_1 \ln C_{t-1} + \lambda_2 \ln Y_{t-1} + \lambda_3 \Delta \ln (Y_{t-1})^2 + \lambda_4 \ln ER_{t-1} \\ &+ \varepsilon_t \quad (5.3)\end{aligned}$$

where β is the short-run coefficient and λ is the long-run multiplier of the underlying ARDL model. The tests for cointegration are carried out by computing the joint significance of the lagged levels of the variables using the F-test (or Wald statistic). The null hypothesis of no cointegration is defined by H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$ against the alternative hypothesis H_1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq 0$. The CVs for the F-statistic are non-standard under the null and were originally derived by Pesaran et al. (2001) and later modified by Narayan (2005) to accommodate small sample sizes. There are two sets of CVs. The first set assumes that all of the variables included in the ARDL model are *I(0)*, whereas the second set uses the assumption that the variables are *I(1)*. If the computed F-statistic exceeds the upper-bounds CVs, then the null hypothesis of no long-run relationship is rejected. If the computed F-statistic falls below the lower-bounds CVs, then the null hypothesis of no long-run relationship is not rejected. However, if the computed F-statistic falls between the lower- and upper-bound CVs, then no conclusion about long-run relationships can be drawn unless we know whether the series were *I(0)* or *I(1)* (Pesaran and Pesaran, 2010). In the presence of strong cointegration between variables, Neuhaus (2006) argues that the problems with multicollinearity can be disregarded.

Choosing the optimal lag order of the underlying UREC model is of primary importance. The lag order should be high enough to reduce the residual serial correlation problems. At the same time, however, it should be low enough that the conditional error-correction model is not subject to over-parameterization problems (Pesaran et al., 2001). This paper uses the Akaike Information Criterion (AIC) and Schwarz's Bayesian criterion (SBC) to select the optimal lag order of the model. The preferred model is the one that has the smallest value of AIC and SBC. However, these two methods might provide different lag structures for the ARDL model because AIC tends to select maximum relevant lag length, whereas SBC tends to select the smallest possible lag length, resulting in a somewhat parsimonious model. In such a case, we prefer to use the AIC information criteria to prevent the model from being under-fit, although there might be a risk of over-fitting the model.

Having found the evidence of cointegration, the long-run relationship between variables is then estimated using the following equation:

$$\ln C_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \ln C_{t-i} + \sum_{i=0}^{q} \beta_{2i} \ln Y_{t-i} + \sum_{i=0}^{r} \beta_{3i} \ln(Y_{t-1})^2 + \sum_{i=0}^{s} \beta_{4i} \ln ER_{t-i} + \varepsilon_t \qquad (5.4)$$

Next, the short-run interactions between variables are estimated by using the following error-correction model:

$$\Delta \ln C_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln C_{t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{r} \beta_{3i} \Delta \ln(Y_{t-1})^2 + \sum_{i=0}^{s} \beta_{4i} \Delta \ln ER_{t-i} + \pi \, ECT_{t-1} + \varepsilon_t \qquad (5.5)$$

where π is the speed adjustment parameter and ECT_{t-1} is the error correction term with lag. The lagged error-correction term measures the speed of adjustment of the endogenous variable when there is a shock in equilibrium. The coefficient of the lagged error correction term is expected to be negative and statistically significant.

Post-estimation diagnostic tests such as serial correlation, normality, heteroskedasticity and functional form tests are conducted to ensure the robustness of the model. In addition, we also conduct the stability test, i.e., cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ), to confirm the model’s stability.

5.5 Evaluating the evidence of the EKC hypothesis

Our evaluation starts with an examination of the integration properties of the variables by performing unit root tests. Although the bounds test approach does not require that all variables are *I(1)*, it is necessary to validate that none of the variables is integrated in order 2 (*I(2)*). This is because in the presence of the *I(2)* variable, the results of the F-test would be spurious. We use the augmented Dickey-Fuller (ADF), Kwiatkowski-Phillips-Schimdt-Shin (KPSS) and breakpoint unit root tests to test the stationarity of the data. In the ADF and breakpoint unit root tests, the null hypothesis of the series has a unit root that is tested against the alternative of stationarity. Conversely, the KPSS test has a null hypothesis of stationarity. The lag lengths of the ADF and breakpoint unit root test are selected based on the Schwarz Information Criterion. The bandwidth selection of the KPSS test is based on the Andrews method. The results of the unit root tests that are provided in Table 5.1 show that after taking the first difference, all of the variables were confirmed to be stationary. Therefore, we can conclude that all the variables used in this study are not *I(2)*.

The next step is to examine the existence of a long-run relationship between variables by using Equation (3). We conduct the cointegration analysis for both linear and quadratic forms. In the first and second cases, we assume a linear form of the long-run relationship between environmental quality and income by controlling energy consumption and both energy consumption and TFP, respectively. In the third and fourth cases, we assume a quadratic relationship between those variables by controlling energy consumption and both energy consumption and TFP, respectively. Before we carry on with cointegration analysis, we need to determine the optimal lag length to be used in the ARDL model. For this

Table 5.1 Unit root test results

Variables	**ADF**		**Breakpoint unit root test**		**KPPS**	
	No Trend	**Trend**	**No Trend**	**Trend**	**No Trend**	**Trend**
Levels						
ln C	-1.612036	-2.906569	-2.874843	-3.760061	0.773246[a]	0.104321[a]
ln Y	-1.583793	-2.062575	-2.049436	-7.608414	0.580830[b]	0.151892[b]
ln Y^2	-1.095478	-2.195491	-1.803745	-7.772209	0.687917[b]	0.146254[b]
ln ER	-0.821178	-2.172115	-3.471982	-6.143338[a]	0.519907[b]	0.120563[c]
ln EC	-0.606822	-1.694119	-5.509523[a]	-5.442050[a]	0.881272[a]	0.111969
ln TFP	-1.737774	-2.439344	-5.409033[a]	-8.424761[a]	0.263024	0.165459
First Differences						
ln C	-5.740083[a]	-5.784033[a]	-7.106165[a]	-7.040115[a]	0.132253	0.041451
ln Y	-4.518360[a]	-4.585807[a]	-9.945942[a]	-9.692768[a]	0.192859	0.060720
ln Y^2	-4.583948[a]	-4.570627[a]	-10.33277[a]	-10.28274[a]	0.121298	0.060339
ln ER	-8.151052[a]	-8.158039[a]	-9.406657[a]	-9.191273[a]	0.099847	0.082047
ln EC	-6.146892[a]	-6.093122[a]	-8.178754[a]	-7.967713[a]	0.100151	0.084858
ln TFP	-4.073000[a]	-4.187022 [b]	-6.833788[a]	-6.828087[a]	0.274802	0.086479

Notes: [a] , [b] and [c], denotes statistical significance at 1 percent, 5 percent and 10 percent levels, respectively.

purpose, we are using the AIC and SBC information criteria. Table 5.2 provides the top 5 models that minimize the AIC and SBC values by setting the maximum lag order at 4. From Table 5.2, we can see that the AIC and SBC suggest different model specifications, but we prefer to use the model that is suggested by AIC to avoid oversimplifying the model. Thus, we have ARDL (2,4,0,0) for Case I, ARDL (2,4,2,0,0) for Case II, ARDL (2,4,3,0,0) for Case III, and ARDL (2,0,4,2,0,0) for Case IV.

Table 5.2 Model selection summary

Linear Model							
Case I				**Case II**			
AIC		**SBC**		**AIC**		**SBC**	
Value	**ARDL**	**Value**	**ARDL**	**Value**	**ARDL**	**Value**	**ARDL**
-2.939205	2,4,0,0	-2.523032	1,1,0,0	-3.014144	2,4,2,0,0	-2.526268	2,1,0,0,2
-2.923381	2,4,2,0	-2.499339	2,4,0,0	-2.987955	2,4,3,0,0	-2.508123	2,1,0,0,0
-2.907610	2,4,1,0	-2.487009	2,2,0,0	-2.985024	2,4,2,0,2	-2.499095	2,2,0,0,0
-2.897030	2,4,3,0	-2.478187	2,1,0,0	-2.983663	2,4,2,0,4	-2.497702	2,0,0,0,2
-2.895722	3,4,2,0	-2.431032	1,2,0,0	-2.980141	2,4,0,0,0	-2.496335	1,1,0,0,0

Quadratic Model							
Case III				**Case IV**			
AIC		**SBC**		**AIC**		**SBC**	
Value	**ARDL**	**Value**	**ARDL**	**Value**	**ARDL**	**Value**	**ARDL**
-3.014755	2,4,3,0,0	-2.438107	1,0,1,0,0	-3.157073	2,0,4,2,0,0	-3.150493	2,0,3,2,0,0
-3.010064	2,3,4,0,0	-2.432490	1,1,0,0,0	-3.150493	2,0,3,2,0,0	-3.135855	2,3,0,2,0,0
-3.004513	3,4,3,0,0	-2.418595	2,0,4,0,0	-3.143731	2,4,0,2,0,0	-3.157073	2,0,4,2,0,0
-3.001501	3,3,4,0,0	-2.407066	2,0,2,0,0	-3.142016	2,4,3,0,0,0	-3.060562	3,0,1,2,0,0
-2.978169	2,4,4,0,0	-2.404817	2,4,0,0,0	-3.141281	2,3,4,0,0,0	-3.058395	3,1,2,0,0,0

By using the aforementioned ARDL model specifications, we calculate the joint significance of the long-run coefficient of the ARDL model in Equation (3). The results of the F-test are given in Table 5.3. From Table 5.3, we can see that for case I, the F-statistic exceeds the 10% upper bounds CVs, whereas for cases II, III and IV, the F-statistics exceed the 5% upper bounds CVs. Thus, we can reject the null hypothesis of no long-run relationship. After conforming that there is no evidence against cointegration, we estimate the long- and short-run interactions between variables by using Equations (4) and (5). The results of the long- and short-run estimations in the error correction representations are provided in Tables 5.4 and 5.5, respectively.

	Linear Model				**Quadratic Model**			
	Case I		**Case II**		**Case III**		**Case IV**	
	Value	**k**	**Value**	**k**	**Value**	**k**	**Value**	**k**
F-statistic	4.570496	3	5.545779	4	4.585547	4	5.332040	5
Critical Values Bounds*	I_0	I_1	I_0	I_1	I_0	I_1	I_0	I_1
10%	2.933	4.020	2.660	3.838	2.660	3.838	2.483	3.708
5%	3.548	4.803	3.202	4.544	3.202	4.544	2.962	4.338
1%	5.018	6.610	4.428	6.250	4.428	6.250	4.045	5.898

Notes: * Based on Narayan's critical values (Narayan, 2005), for the case of unrestricted intercept and no trend.

Table 5.3 Bound test for cointegration

Variables	Linear Model		Quadratic Model	
	Case I: ARDL (2,4,0,0)	**Case II: ARDL (2,4,2,0,0)**	**Case III: ARDL (2,4,3,0,0)**	**Case IV: ARDL (2,0,4,2,0,0)**
ln *Y*	0.87243 (0.26785)^a	1.03806 (0.23162)^a	-0.15389 (1.53462)	4.71954 (1.44783)^a
ln Y^2	-	-	0.05150 (0.11063)	-0.26358 (0.10351)^a
ln *ER*	-0.20348 (0.05695)^a	-0.22232 (0.05170)^a	-0.18612 (0.05606)^a	-0.27757 (0.04477)^a
ln *EC*	0.67124 (0.29423)^b	0.49938 (0.28942)^c	0.79649 (0.33321)^b	0.43628 (0.21826)^c
ln *TFP*	-	-0.19052 (0.08940)^b	-	-0.38593 (0.09883)^a
C	-9.41814 (0.65742)^a	-9.56622 (0.68880)^a	-5.66175 (5.35130)	-21.95706 (4.89835)^a
R-squared	0.98872	0.99114	0.99162	0.99273
Adjusted R-squared	0.98482	0.98652	0.98668	0.98844
SE of regression	0.04960	0.04674	0.04646	0.04327
F-statistic	253.2984^a	214.5052^a	200.4357^a	231.3499^a
AIC	-2.93920	-3.01414	-3.01475	-3.15707
D-W statistic	1.85638	1.89591	1.85166	2.04092
Diagnostic tests				
Serial correlation	$\chi^2_{(1)} = 0.05777$ (P = 0.81)	$\chi^2_{(1)} = 0.23135$ (P = 0.63)	$\chi^2_{(1)} = 0.00150$ (P = 0.97)	$\chi^2_{(1)} = 0.21811$ (P = 0.64)
Functional form	$\chi^2_{(1)} = 0.00404$ (P = 0.95)	$\chi^2_{(1)} = 5.94874$ (P = 0.02)	$\chi^2_{(1)} = 2.06983$ (P = 0.17)	$\chi^2_{(1)} = 1.79716$ (P = 0.19)
Normality	$\chi^2_{(1)} = 0.80972$ (P = 0.67)	$\chi^2_{(1)} = 0.52438$ (P = 0.77)	$\chi^2_{(1)} = 0.64434$ (P = 0.72)	$\chi^2_{(1)} = 0.10241$ (P = 0.95)
Heteroscedasticity	$\chi^2_{(1)} = 2.85938$ (P = 0.97)	$\chi^2_{(1)} = 4.75136$ (P = 0.97)	$\chi^2_{(1)} = 4.01572$ (P = 0.99)	$\chi^2_{(1)} = 4.38389$ (P = 0.99)

Notes:

1. ^{a} and ^{b}, denotes statistical significance at 1 percent and 5 percent levels, respectively.
2. The numbers in parentheses are standard errors.

Table 5.4 Long-run estimates based on ARDL model

Variables	Linear Model		Quadratic Model	
	Case I: ARDL (2,4,0,0)	**Case II: ARDL (2,4,2,0,0)**	**Case III: ARDL (2,4,3,0,0)**	**Case IV: ARDL (2,0,4,2,0,0)**
$\Delta \ln C_{t-1}$	0.39469 (0.14831)^b	0.46932 (0.13566)^a	0.51511 (0.15043)^a	0.60922 (0.13579)^a
$\Delta \ln Y$	1.46985 (0.27051)^a	1.70191 (0.32813)^a	-11.50687 (7.70250)	4.08808 (2.75265)
$\Delta \ln Y^2$	-	-	0.92997 (0.54977)	-0.15540 (0.19863)
$\Delta \ln ER$	-0.13220 (0.03939)^a	-0.15842 (0.04558)^a	-0.12191 (0.03925)^b	-0.19161 (0.04311)^b
$\Delta \ln EC$	0.43610 (0.18534)^b	0.40899 (0.22109)^c	0.52170 (0.20920)^b	0.45462 (0.20561)^b
$\Delta \ln TFP$	-	-0.23774 (0.19390)	-	-0.41390 (0.17729)^b
ECT_{t-1}	-0.64969 (0.11766)^a	-0.75155 (0.12663)^a	-0.65500 (0.11102)^a	-0.94820 (0.14237)^a

Notes:

1. ^{a} , ^{b} and ^{c}, denotes statistical significance at 1 percent, 5 percent and 10 percent levels, respectively.
2. The numbers in parentheses are standard errors.

Table 5.5 Short-run estimates based on ARDL model

For the linear model (case I and II), as seen in Tables 5.4 and 5.5, all of the variables are statistically significant and have the correct signs as expected, both in the long run and in the short run. The coefficients of ln Y and Δln Y are positive, implying that both in the long run and in the short run, higher income levels lead to higher CO_2 emissions. However, we find that in both cases, income leads to less carbon dioxide emission. In the long run, income elasticity decreased from 1.47 to 0.87 for case I and from 1.70 to 1.04 for case II. Our finding suggests that over time, economic growth contributes less to carbon dioxide emissions, implying that the environmental benefits of economic growth are likely to be achieved. Although Narayan and Narayan (2010) argue that the cutback in income elasticity over time, similar to the findings in our linear model, is consistent with the EKC hypothesis, Jaunky (2011) and Al-Mulali et al. (2015) argue that this argument is insufficient to support the EKC hypothesis. Our finding contradicts the earlier result from Narayan and Narayan (2010) showing higher long-run income elasticity for the case of Indonesia. This contradiction likely arose because Narayan and Narayan (2010) use a smaller sample size and a somewhat parsimonious model of income level and CO_2 emissions, disregarding the possible impacts of energy consumption and renewable energy sources on CO_2 emissions.

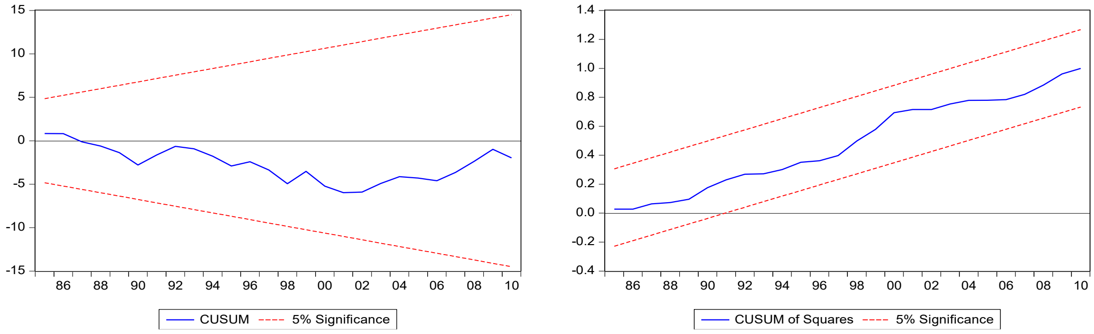
Another important finding from our model in case I is that the impact of electricity production from renewables on CO_2 emissions is negative both in the short run and in the long run, implying that the level of CO_2 emissions declines as the share of renewable energy increases. This in line with the findings of Sulaiman et al. (2013) for the case of Malaysia and the findings of Bölük and Mert (2015) for the case of Turkey. The beneficial effects of renewable energy sources on environmental quality are likely to be achieved in the long run because its long-run coefficient is higher than its short-run coefficient. However, the long-run elasticity of renewable energy is considerably lower than that of energy consumption and economic growth. Thus, the beneficial effects of renewable energy sources might be obscured by the increasing level of CO_2 emissions caused by increasing economic activities and higher energy consumption. Chiu and Chang (2009) suggest a threshold point that must be attained for renewable energy to begin to have a favorable impact on environment. They argue that to make a noteworthy contribution to CO_2 emissions reduction, the share of renewable energy should be at least 8.4 percent of total energy supply. Currently, the share of renewable energy is only approximately 3.8 percent of Indonesia's total energy mix. However, if we only consider the electricity sector, which is responsible for more than 38 percent of CO_2 emissions, the share of renewable energy is more than 11 percent of total electricity generation, which is higher than the suggested threshold point of 8.4 percent. Therefore, the effect of electricity production from renewable energy sources on CO_2 emissions reduction should be observed, as explained by our model.

The positive coefficient of $\ln EC$ and $\Delta \ln EC$ imply that energy consumption positively influences the level of CO_2 emissions both in the long run and in the short run. This is not a surprising result: Indonesia's energy sector relies heavily on fossil fuels, accounting for approximately 96 percent of total primary energy consumption (NEC, 2015). This finding is consistent with that of Ang (2007) for the case of France and Saboori et al. (2012b) for the case of Indonesia. We also find that the elasticity of energy consumption in the long run is greater than elasticity in the short run, implying inefficiency in energy consumption. For case II, however, taking TFP into account in our model, we find only a slight increase in the elasticity of energy consumption in the long run. The negative and significant coefficient of TFP indicates that adopting a more efficient technology has beneficial effects on the environment, either by directly reducing the level of emissions or by increasing the efficiency of energy consumption. This finding supports Stern (2004) argument, which proposes that a general increase in TFP has beneficial side effects for the environment through decreased emissions per unit of output.

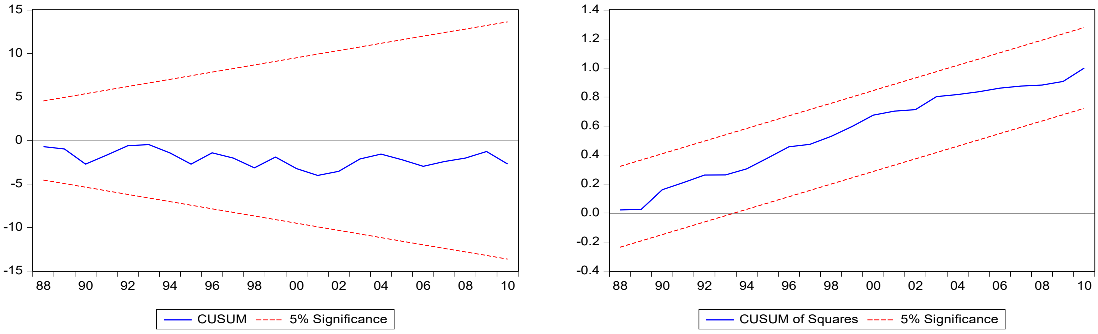
We also attempt to evaluate the EKC-type relationship by using the traditional quadratic model (case III and IV). From Tables 5.4 and 5.5, we can see that, in general, the quadratic model provides similar results, particularly for the impacts of energy consumption, electricity production from renewables and TFP. Nevertheless, our findings on the impact of income level on level of CO_2 emissions show an interesting result. For case III, both in the short run and in the long run, the coefficients of ln Y and ln Y^2 are statistically not significant. There is a possibility that these variables fail to attain statistical significance because of the presence of multicollinearity, as advised by Narayan and Narayan (2010). However, by introducing variable *TFP* into our model (case IV) we find significant impacts of income level on CO_2 emissions in the long run. The negative and significant coefficient of ln Y^2 suggests an inverted U-shaped relationship between income level and CO_2 emissions, which is consistent with the EKC hypothesis. From the long-run estimates, the turning point is estimated to be $exp(\beta_1/|2\ \ \beta_2|) \cong 7{,}729$ USD per capita. The estimated turning point is relatively plausible, although it lies outside of the sample period (the highest value of GDP per capita in our sample is 1,570 USD). Several previous studies, such as Saboori and Sulaiman (2013) for the case of Malaysia and Bölük and Mert (2015) for the case of Turkey, have also reported EKC turning points that lie outside the observed sample period. Additionally, Iwata et al. (2010) argue that for developing countries, there is a higher possibility that the EKC turning point will be found outside of the observed sample period.

From the short-run estimates in Table 5.5, we can see that the coefficients of the lagged error-correction term (ECT_{t-1}) in all cases are negative and statistically significant, as they should be. These results further establish the cointegration between variables. In addition, their absolute values are quite high, indicating a relatively high speed of adjustment in the presence of any shock to the equilibrium.

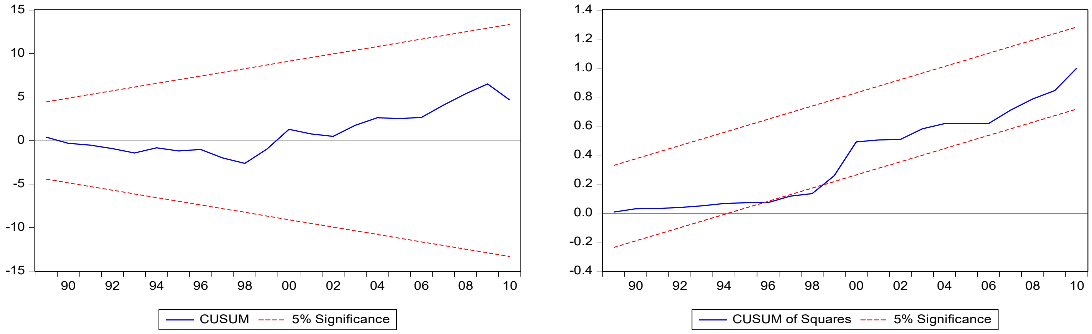
Case I



Case II



Case III



Case IV

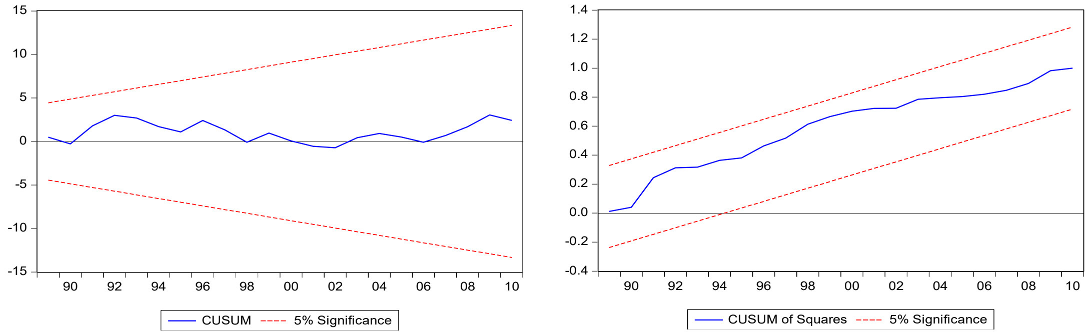


Figure 5.3 Stability of the models based on the plot of CUSUM and CUSUMSQ of recursive residual

The post-diagnostic tests of our models are reported in Table 5.4. We find no evidence of serial correlation, non-normality and heteroskedasticity in all cases. However, we cannot reject the null hypothesis of no miss-specification of functional form in case II. This result suggests that the quadratic form of the EKC-type relationship given in case IV is preferable to that of the linear form, although the model is likely to suffer from the problems with multicollinearity. However, Asteriou and Hall (2015) argue that even in the presence of imperfect multicollinearity, the estimated coefficients remain unbiased. In addition, to test the stability of the estimated models, the CUSUM and CUSUMSQ tests were employed. The plots of both CUSUM and CUSUMSQ tests, which are given in Figure 5.3, are within the 5% critical bounds, indicating that the estimated parameters in all cases are stable over the periods.

5.6 Conclusions and policy implications

The objective of this paper was to estimate the EKC for the case of Indonesia by considering electricity production from renewable energy sources for the period of 1971-2010. To avoid omitted variable bias, we considered the level of energy consumption and TFP in our model to capture the scale and technique effect. We used both the linear and traditional quadratic model to test the EKC hypothesis. For this purpose, we applied the Autoregressive Distributed Lag (ARDL) bounds testing approach proposed by Pesaran et al. (2001). Given the relatively small sample size in our current study (40 observations), we adopted the critical values reported in Narayan (2005) for testing the cointegration between variables.

From the estimation results, we found evidence supporting the EKC hypothesis for the case of Indonesia. Although our linear form of the model showed a positive relationship between CO_2 emissions and income level, we found that long-run income elasticity has decreased over time, implying that environmental benefits of economic growth are likely to be achieved. However, this finding is not considered as a significant support for the EKC hypothesis. Our quadratic form of the model, on the other hand, showed strong evidence of the EKC hypothesis. The estimated turning point was found to be $exp(\beta_1/|2\ \beta_2|) \cong 7{,}729$ USD per capita, which lies outside our sample period. Electricity generation from renewable energy sources was found to have a significant and favorable impact on CO_2 emissions reduction both in the short run and in the long run. In contrast, energy consumption was associated with higher levels of CO_2 emissions both in the short run and in the long run. Finally, we also found that an increase in TFP leads to a decrease in CO_2 emissions both in the short run and in the long run.

Although suggesting new policies is beyond the scope of this paper, our findings highlight some important policy implications. First, evidence of the EKC hypothesis does not necessarily imply that environmental benefits from economic growth can be achieved without any policy enactment. The huge gap between current economic level and the estimated turning point indicate that the GoI should evaluate the efficacy of current energy and environmental policies to obtain an EKC that is lower and flatter than our estimated turning point would suggest.

Second, we found that the long-run impact of energy consumption on CO_2 emissions level is considerably higher than its short-run effect. Our finding indicates an inefficiency in energy consumption that leads to further environmental deterioration. Therefore, current energy and environmental policies must be accompanied by other possible strategies that will encourage more efficient energy use. For instance, the GoI's attempts to gradually decrease subsidies on fossil fuels and electricity should be maintained, though this might not be a popular policy. In exchange, the GoI should make new investments in energy infrastructures that will be beneficial not only for improving energy efficiency but also for stimulating economic development. Additionally, the GoI should provide incentives for encouraging the adoption of new technologies that are both cleaner and more efficient. Our finding showed that increasing productivity provides beneficial impacts for CO_2 emissions reduction, which in turn leads to the initiation of the EKC pattern.

Third, the favorable impacts of electricity production via renewable energies on CO_2 emissions reduction indicate that environmental sustainability might be achieved by increasing the share of renewable energies in the electricity generation mix. Our findings further emphasize the significant roles of NRE sources in promoting a sustainable development path, particularly in the context of the 2015 Paris agreement on climate change. Encouraging the development of NRE sources will be very beneficial not only for ensuring the security of the energy supply and reducing the high dependency on fossil fuels but also for supporting the GoI's commitment to reduce CO_2 emissions. This in turn will lead to a lower and flatter EKC than our estimated turning point would suggest. Therefore, instead of relying heavily on coal-fired power plants to boost Indonesia's current electricity generation capacity, the GoI should exert greater effort to explore the potential of NRE sources. However, there are some technical barriers, such as the intermittent nature of the output, that make it difficult for renewable energy sources alone to replace the dominant role of fossil fuels. Therefore, the GoI should consider backing up its renewable energy system with a reliable low-carbon technology, such as nuclear power, to form a tight energy coupling system that can produce renewable electricity on a large scale in a sustainable manner (Soentono and Aziz, 2008). However, the implementation of nuclear energy-related policies should be carried out cautiously. The decision-making process should be based on a comprehensive analysis highlighting not only the beneficial impacts of nuclear energy on CO_2 emissions reduction and energy security but also the potential risks that can arise from the utilization of nuclear energy.

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Chapter 6 Public acceptance of nuclear power plants in Indonesia: Portraying the role of a multilevel governance system

6.1 Introduction

Indonesia is an emerging economy with the fourth largest population in the world. In parallel with its economic growth, which grew remarkably at an average rate of 5.4 percent per year, the demand for electricity has rapidly increased at an annual average rate of 6.2 percent over the last decade (BPPT, 2014). The strong linkage between electricity consumption and wealth creation (Ferguson et al., 2000) has urged the government of Indonesia to boost its electricity generation capacity by launching the Electricity Fast Track (EFT) program. However, the EFT program still relies heavily on coal-fired power plants, which is likely to uphold the high dependency on fossil fuels and increase the trend of greenhouse gas (GHG) emission in the near future (BPPT, 2014). The government of Indonesia (GoI) has attempted to reduce GHG emissions by increasing the share of new and renewable energy (NRE) in the national energy mix. According to Government Regulation 79/2014 regarding the national energy policy, the share of NRE will account for at least 23 percent of the total energy mix by 2025. Despite the intense and long-running debate about the pros and cons of nuclear energy utilization (see, for instance (Hong et al., 2014; Lehtveer and Hedenus, 2015; Marshall, 2012; Meskens, 2013; Soentono and Aziz, 2008)), nuclear power plants (NPPs) are also considered one of the feasible options for expediting electricity generation in a more sustainable way. Combined with other low-carbon-energy technologies, nuclear energy is expected to create a flatter and more achievable turning point in the environmental Kuznets curve, which will lead to sustainability (Sugiawan and Managi, 2016).

However, the low level of public acceptance has made the deployment of NPP projects in Indonesia experience a number of substantial delays. Public opposition to NPP has also become a major concern in many countries, particularly after the Fukushima nuclear accident (see, for instance (Kim et al., 2013; Kim et al., 2014)). Previous studies show that there are at least two major reasons behind the strong opposition to nuclear energy. First, nuclear energy is considered a high-risk technology that is usually associated with potential hazards from radioactivity, nuclear accidents, or even nuclear weapons (Adamantiades and Kessides, 2009; Siegrist and Visschers, 2013). Second, many nuclear decision-making processes have focused only on technological and economical aspects, disregarding the importance of public engagement that will eventually lead to public distrust (Mah et al., 2014; NEA-OECD, 2010; Sohn et al., 2001). This experience suggests the necessity to comprehend how perceptions of nuclear energy among stakeholders are developed and to identify the factors that positively influence their acceptance, since the decision-making process in nuclear-related projects involves a wide range of stakeholders with different kinds of background, knowledge, and interests.

Previous studies (e.g., (Baskaran et al., 2013; Huijts et al., 2012; Park and Ohm, 2014; Perlaviciute and Steg, 2014; Savvanidou et al., 2010; Wüstenhagen et al., 2007)) have investigated the determinants of public acceptance of energy technology and found that trust in the managing authorities is one of the key factors that positively influences the acceptance of new energy technology. Furthermore, with a specific reference to nuclear energy, Kim et al. (2014) found that although trust in the managing authorities is not a driver for the strong acceptance of nuclear energy, it is essential for moderating opposition to nuclear energy. However, the aspect of trust in their study referred only to the nuclear energy authorities which might not be applicable in a highly decentralized country such as Indonesia. The implementation of a nuclear energy policy in Indonesia is more challenging since it involves multilevel managing authorities, including the central government, nuclear energy authorities and the local government. Therefore, the context of trust should be extended not only to the nuclear energy authorities but also to the central and local governments that also have significant roles in the decision-making process. To our knowledge, there is no comprehensive study that has investigated the different impact of trust in these authorities in shaping community acceptance of nuclear energy. By making use of the data from public opinion polls conducted by the National Nuclear Energy Agency of Indonesia (BATAN) in 2010 and 2011, this paper aims to fill the gap. The results from this study are very important for establishing the social sustainability of nuclear energy policy in Indonesia. Additionally, the findings from this study might also be applicable to the deployment of other new energy technologies.

6.1.1 Nuclear Energy Development in Indonesia

Nuclear energy-related activity in Indonesia is well established and dates back to 1954 with the establishment of the State Committee for the Investigation of Radioactivity, having a main duty to observe the possibility of radioactive fall-out from nuclear weapon tests in the Pacific Ocean in Indonesia Territory. On 5th December 1958, the GoI established the Atomic Energy Council and the Atomic Energy Institute which had the task of developing the utilization of nuclear energy for improving national welfare. In 1964, according to Law No.31/1964 regarding the Basic Stipulations on Atomic Energy, the Atomic Energy Institute was renamed the National Atomic Energy Agency. To proceed with the development of the nuclear power sector, the GoI issued Law No.10/1997 regarding the Utilization of Nuclear Energy which stipulated the separation between the implementing agency, which was assigned to the National Nuclear Energy Agency (BATAN), and the regulatory body, which was assigned to the Nuclear Energy Regulatory Agency (BAPETEN).

Indonesia had its first nuclear research reactor in the early 1960s with the construction of the TRIGA Mark II facility in Bandung. This facility was followed by the construction of the Kartini research reactor in Yogyakarta, which started its operation in 1979, and a 30 MW multipurpose research reactor in Serpong Nuclear Complex, which came into operation in 1987. Having experience with the construction, commissioning, operation, maintenance and utilization of research reactors, the GoI attempted to start an NPP project in the mid-1970s by conducting the first prefeasibility study for the introduction of an NPP which was assisted by the government of Italy. Following this study, the GoI decided to postpone the project until the nuclear research facilities in Serpong became fully operational. In 1989, the GoI decided to carry out a new and more comprehensive NPP feasibility study on the Muria Peninsula as a candidate site for NPPs. The study was completed in 1996, concluding that the Ujung Lemahabang area, which is located at the tip of Muria Peninsula, was the best candidate for the NPP site, evaluated from both technical and economic aspects. The study also suggested that the first NPP should be introduced in the early 2000s to the Java-Bali electric system (Soentono, 1997). BATAN had also completed the second feasibility studies for NPPs on Bangka Island, Bangka Belitung Islands Province, in 2013, suggesting two potential sites for NPPs.

However, the Integrated Nuclear Infrastructure Review (INIR) Mission which was conducted in 2009 by the International Atomic Energy Agency (IAEA) concluded that although the GoI had fulfilled most of the infrastructure requirements in the first phase of the NPP project and was ready to proceed to the second phase, there were three aspects of infrastructure issues that required significant actions and further improvement i.e., national position, management, and stakeholder involvement (BATAN, 2014). BATAN is aware that stakeholder involvement is one of the important factors for achieving the social sustainability of nuclear energy policy. A lack of stakeholder involvement in the decision-making process is likely to create public distrust that will eventually lead to public opposition to nuclear energy (NEA-OECD, 2010; Sohn et al., 2001). In regard to this matter, BATAN had been carrying out sustained and concerted efforts to gain higher public support for NPPs. Effective communication with key stakeholders has been carried out in an extensive manner. BATAN also provides clear and detailed information on nuclear energy that can be easily accessed by the public through mass media. In addition to these efforts, a series of nuclear energy-related events is regularly held by BATAN to widely disseminate nuclear energy to the public and to encourage greater public involvement in the decision-making process. Based on the evaluation of the readiness of its supporting infrastructure, the first NPP in Indonesia is expected to be ready for commissioning in 2027, with an initial capacity of 2,000 MW. The capacity is then expected to increase up to 12,000 MW in 2050 (BATAN, 2014).

6.2 Determinants of acceptance of nuclear power plants

Following previous studies by Huijts et al. (2012), Kim et al. (2014), Sauter and Watson (2007) and van Rijnsoever et al. (2015), we define acceptance as supportive behavior toward a technology that can be expressed in various attitudes, ranging from fairly passive agreement to an active campaign for the use of a technology. Based on the degree of involvement, Wüstenhagen et al. (2007) further differentiated acceptance into public acceptance and community acceptance. Public acceptance refers to the aggregate acceptance of individuals nationwide, with respect to their role as citizens, which are unlikely to be affected directly by the implementation of a policy, while community acceptance refers to the specific acceptance of local stakeholders who are likely to experience the direct impacts from the placement of the energy technology (Wüstenhagen et al., 2007). Both public and community acceptance play an important role in determining the social sustainability of energy policy. However, in the presence of the *not in my backyard* (NIMBY) effect, there will be a noticeable difference between public and community acceptance. For instance, Van der Horst (2007) and Yuan et al. (2015) found a less supportive attitude toward energy technology from the local community which was associated with NIMBYism. However, Wolsink (2007), Devine-Wright (2007) and Perlaviciute and Steg (2014) argued that there is no such thing such as the NIMBY effect. They believe that the proximity to a site could not simply be blamed as the main cause of local opposition. However, it emerges due to the lack of equity and fairness in the decision making process.

People's attitudes toward energy technology are determined by their net perception of risk or the benefit of the technology, which is influenced by three factors i.e., personal, psychological and contextual factors (Devine-Wright, 2007). Personal factors refer to sociodemographic characteristics such as age, gender and social class. Psychological factors include, among other factors, the level of trust, familiarity with and knowledge of an energy technology. Contextual factors comprise the technological aspects, the spatial proximity to the energy facilities and public engagement. Risks and benefits are two distinct concepts that are negatively correlated and have an inverse relationship in people's minds (Finucane et al., 2000). Furthermore, Slovic et al. (2005) argued that risk and benefit are perceived and evaluated in two different ways. First, risk is perceived through careful analysis by using intellectual ability, such as logic, reason and scientific evidence. This is referred to as 'risk as analysis'. In this way of decision making, people's perceptions of risk or benefit will be greatly influenced by their level of knowledge and familiarity with a technology. Second, risk is perceived by relying on people's feelings and experiences, which are associated with the role of affect heuristics (Finucane et al., 2000; Slovic et al., 2005). This is referred to as 'risk as feelings'. This classification suggests that there will be different manners between well-educated and lay people in evaluating the risks and benefits of a certain energy technology. Well-educated people tend to use their knowledge to perceive and evaluate risks analytically, while lay people, with their limited knowledge, tend to use affect heuristics in the decision-making process. This knowledge gap will lead to different attitudes between well-educated and lay people toward energy technology (Stoutenborough et al., 2013). To address this unfavorable knowledge gap, Chao-jun et al. (2013), Kidd (2013) and Stoutenborough et al. (2013) emphasized the necessity for continuously providing clear and detailed information about energy technology to the public.

In the context of NPPs, which are usually associated with high-risk technologies, acceptance will be greatly influenced by trust in the managing authorities (Bronfman et al., 2012; Huijts et al., 2012; Siegrist and Cvetkovich, 2000). Rousseau et al. (1998) provided a formal definition of trust as follows: "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another". Furthermore, Greenberg (2014) and Xiao et al. (2017) argued that the dimensions of trust cover two essential aspects, i.e., competence and value, which are associated with cognitive and affective trust, respectively. Cognitive trust refers to rational judgement, such as technical ability, expertise and the competency of the managing authorities, while affective trust is associated with emotional judgement, such as the sincerity, trustworthiness and commitment of the managing authorities (Xiao et al., 2017). From these definitions we can see that trust acts as an important aspect that influences people`s judgement on the net perception of risk or benefit of NPPs, which in turn will determine their view of NPPs. A high level of trust in the managing authorities will decrease the perceived risks of nuclear energy which in turn leads to a supportive attitude toward NPPs (Bronfman et al., 2012; Siegrist and Cvetkovich, 2000). On the other hand, a decreased level of trust, which is caused by nuclear accidents, will increase the perceived risk of nuclear energy, which in turn leads to the negative acceptance of nuclear energy (Park and Ohm, 2014; Prati and Zani, 2012; Siegrist et al., 2014). Additionally, if there is lack of appropriate scientific knowledge, familiarity and information about a certain technology, acceptance will be solely influenced by trust in the managing authorities (Bronfman et al., 2012; Huijts et al., 2012; Siegrist and Cvetkovich, 2000). For example, Liu et al. (2008) found that trust in the managing authorities acts as the most prominent factor that directly determines the acceptance of nuclear energy. Furthermore, trust in the managing authorities might also arise from public aspirations for nuclear weapons. Jewell and Ates (2015) argued that nuclear weapon programs might also be associated with a stronger commitment to NPP programs. Such commitment is essential for increasing affective trust in the managing authorities and it eventually leads to a successful introduction of NPP programs, particularly in politically unstable countries.

In a multilevel governance system, the role of trust in the decision-making process becomes more important, particularly in a highly decentralized country such as Indonesia, because controls over the energy policy are not only centralized at the national level but also distributed to the subnational level. Such a multilevel governance system is prone to political conflicts, either horizontal or vertical, between decision makers at each level of the system (Marquardt, 2014). Greenberg (2014) argued that establishing and maintaining trust in every level of the system is an essential aspect that will determine the social sustainability of energy policies either directly or indirectly. He used the Yucca Mountain case as an example of poor energy planning due to the lack of trust between the federal government and the state government. In contrast to the Yucca Mountain case, Greenberg (2014) used the case of Waste Isolation Pilot Plant in New Mexico as a successful example of trust building that involved both the federal government and local officials. The above-mentioned examples justify the significant roles of public engagement in the decision-making process as a beneficial means of communication for improving the substantive quality of a policy, resolving the conflicts of interest among stakeholders and building trust in the managing authorities (Goodfellow et al., 2011; NEA-OECD, 2010).

Although the existing literature has provided a significant contribution in identifying the key factors that determine public acceptance of NPP, there is no study that differentiates the role of multilevel managing authorities i.e., the central government, nuclear energy authorities and local government, in shaping people's attitudes toward NPPs. This paper aims to fill the gap. Specifically, this paper will study to what extent trust in the local government, nuclear energy authorities and central government influences the public acceptance of NPPs in Indonesia. Determining the most dominant authority that influences the acceptance of nuclear energy is very important particularly for developing an effective communication strategy with key stakeholders and determining how nuclear energy policy should be implemented.

6.3 Methodology and data

6.3.1 Data collection

This paper utilizes data from public opinion polls organized by BATAN as part of a nuclear science and technology dissemination project. The survey was carried out in 2010 and 2011. A professional research company was appointed to administer the survey through face-to-face interviews. The respondents were age 15 and older were selected using a multistage random sampling method. The survey was conducted on 22 cities in seven major provinces in Java and the Bali islands. The data containing missing value due to unfinished responses or incomplete demographic information were dropped from the sample, giving a total sample of 5,372 respondents.

The questionnaire was designed by the Center for Dissemination of Nuclear Science and Technology – BATAN. The questionnaire was divided into two parts. In the first part, the respondents were asked about their profile, i.e., age, gender, occupation, educational background and domicile. Meanwhile, in the second part of the questionnaire the respondents were asked about their view of the electricity sector in Indonesia. They were initially asked about their apprehension of the electricity sector in Indonesia. Afterwards, they were asked about their preference for suitable power plants for electricity generation. Finally, the respondents were asked about their personal experience with nuclear energy and their stance on NPPs.

6.3.2 Multinomial logit and path model

To meet the main objectives of this paper, the public's attitude toward NPPs is selected as the dependent variable. The respondents were asked about their view of using NPPs as one of the possible options for generating electricity to prevent an electricity crisis in Indonesia. They responded to this question by choosing 1 out of 5 possible options, i.e., strongly agree, somewhat agree, somewhat disagree, strongly disagree, and ambivalent. The respondents' answers are then coded into three outcome categories. Those who strongly agreed or somewhat agreed with NPPs are assigned a 1. Furthermore, those who strongly disagreed or somewhat disagreed are assigned a 2. Meanwhile, those who were unsure about their stance on NPPs are assigned a 3.

As for the independent variables, some questions from the survey are selected to represent key factors that are likely to be significant predictors of acceptance of NPPs. These included the level of knowledge, information, trust, technical aspect, public engagement, and spatial factors. First, to capture the respondents' knowledge about NPPs, although there were several questions related to this aspect, this paper only selects a specific question asking about the respondents' familiarity with NPPs. Those who were very familiar or somewhat familiar with NPPs are assigned a 1; otherwise, they are assigned a 0. Second, to obtain the data on the role of information, this paper selects several questions that asked whether the respondents had seen, heard or read NPP advertisements on TV, in newspapers, on the Internet and in other media. For simplification, the model differentiates the media campaigns into two types, namely, TV advertisements and non-TV advertisements, which correspond to two dummy variables. Additionally, this paper also investigates the role of information about current energy situations on people's attitudes toward NPPs. The data are obtained from the question about the respondents' opinions about whether Indonesia will likely face an electricity crisis in the near future. All of the variables that represent the role of information are coded as binary variables that take the value of 1 if the respondents confirm the statements/questions or 0 if otherwise.

Third, the data on trust in the managing authorities is obtained from the question asking the respondents' opinion about the trustworthy spokespeople for NPPs. There were several options for answering this question, and each respondent could choose more than one response. The options were classified into four groups. The central government, local government and nuclear energy authorities are our main variables of interest, and each is assigned into one of three distinct groups while the others are classified into the fourth group. These groups correspond to the three dummy variables representing trust. In addition to the dummy variables, we also generate an additional variable to capture the overall trust in the managing authorities, which had a range of values from 0 to 3. We assign a value of 0 if the respondent chose other than the three managing authorities as the trustworthy spokespeople for NPPs. Furthermore, we assign a value of 1, 2 or 3 for each managing authority that was chosen as the trustworthy spokespeople for NPPs. These two sets of trust variables will be estimated in two separate models so that we can draw a distinction between general and specific trust in the managing authorities. Fourth, the data on technical evaluation are collected from the question regarding the type of power plant that can produce a large amount of electricity without GHG emissions. The respondents who chose NPPs are assigned a 1, and the others are assigned a 0. Regarding public engagement, the data are obtained from the question about the respondents' involvement in the nuclear science and technology dissemination events that were organized by BATAN. Those who had participated in an event take the value of 1; otherwise, they take the value of 0. Finally, the spatial factor is captured by the domicile of the respondents. Those who reside in Jepara vicinity, which has been selected as the potential site of an NPP, take the value of 1; otherwise, the respondents are assigned a 0. Additionally, it is also necessary to control for the sociodemographic characteristics of the respondents, such as age, gender and level of education. Table 6.1 provides the description of the variables that are used in this model followed by their mean values and standard deviation.

We construct two multinomial logistic models by using the aforementioned variables to identify the significant predictors of the acceptance of NPPs and to predict the effect of the explanatory variables on the acceptance of NPPs. Our first model uses a single variable of trust aimed primarily at capturing the impact of general trust in the managing authorities on the acceptance of NPPs. For the second model, we use three dummy variables of trust to identify the different impacts of trust in the local government, central government and nuclear energy authorities on

Table 6.1 Descriptive statistics of variables

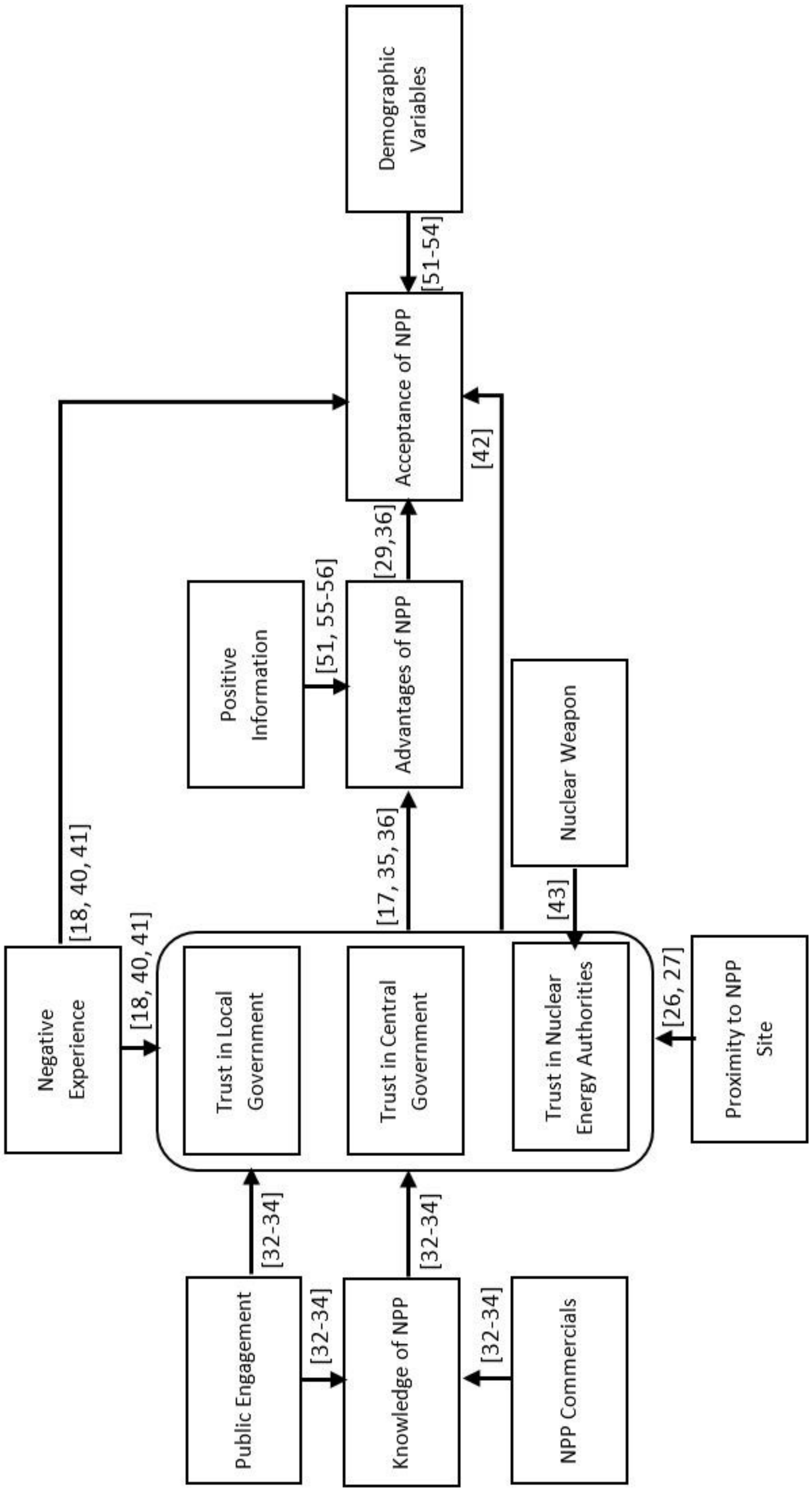
Variables	Description	Number of Observations
Dependent variable		
NPPM	1 if respondent is in favor of NPP, 2 if respondent is against NPP, 3 if respondent is unsure about his/her opinion about NPP	1 = 2697 2 = 828 3 = 1847
Independent variable		
TrustGEN	1, 2 or 3 depend on the number of managing authority which were chosen as the trustworthy spokespeople for NPP, 0 otherwise	0 = 875 1 = 2439 2 = 1486 3 = 572
TrustBATAN	1 if respondent thinks that BATAN is a trustworthy spokespeople for NPP project, 0 otherwise	0 = 2705 1 = 2667
TrustCentGov	1 if respondent thinks that the central government is a trustworthy spokespeople for NPP project, 0 otherwise	0 = 2743 1 = 2629
TrustLocGov	1 if respondent thinks that the local government is a trustworthy spokespeople for NPP project, 0 otherwise	0 = 3541 1 = 1831
PubEng	1 if respondent has been participated in nuclear science and technology dissemination events, 0 otherwise	0 = 1901 1 = 3471
Adv	1 if respondent have heard, seen, or read advertisements (other than TV commercials) on NPP, 0 otherwise	0 = 4619 1 = 753
TVCom	1 if respondent have seen TV commercials about NPP, 0 otherwise	0 = 4217 1 = 1155
ElecCri	1 if respondent believes that Indonesia is going to face electricity crisis in the near future	0 = 1846 1 = 3526
KnowNPP	1 if respondent is familiar with NPP, 0 otherwise	0 = 4644 1 = 728
AdvNPP	1 if respondent believe that compared to other sources of electricity generation, NPP provides a larger amount electricity without emitting GHG, 0 otherwise	0 = 4867 1 = 505
Female	1 if respondent is a female, 0 otherwise	0 = 2885 1 = 2487
Age	Respondent age group (8 age groups, 1=<15 years old, 2= 15-17 years old, 3=18-25 years old, 4=26-35 years old, 5=36-45 years old, 6=46-55 years old, 7=56-65 years old, 8= >65 years old)	1=179; 2=523; 3=1136; 4=1410; 5=1180; 6=650; 7=261; 8=33
Educ	Respondent education level (8 education level; 1= not attending school, 2 = elementary school, 3 = junior high, 4 = senior high, 5 = diploma, 6 = diploma III, 7 = under graduate, 8 = post graduate)	1=134; 2=894; 3=1183; 4=2221; 5=82; 6=169; 7=597; 8=92
NPPSite	1 if respondent resides in Jepara city, 0 otherwise	0 = 5198 1 = 174
Year2011	1 if the sample is collected in 2011, 0 otherwise	0 = 2673 1 = 2699
NucWeap	1 if respondent chose nuclear weapon for the potential use of nuclear energy, 0 otherwise	0 = 3722 1 = 1650

the acceptance of NPPs. Additionally, to further study the interactions between trust and other independent variables in determining the acceptance of NPPs, this paper uses a path model, as shown in Figure 6.1. In addition to having direct effects on the acceptance of NPPs, trust might also influence the perceived benefit of NPPs, which in turn will determine people's attitudes toward NPPs. Trust is also assumed to be influenced by people's knowledge of NPPs, proximity to the future site of the NPP and negative experiences with nuclear accidents. Furthermore, knowledge of NPPs is determined by the level of education and public information on NPPs, which is obtained from TV commercials, advertising, and involvement in nuclear-related dissemination events. Since our path model involves binary responses, the results are estimated by using a generalized structural equation model (GSEM).

6.4 Determinants of acceptance of NPPs in Indonesia

The 2010 survey revealed that before the Fukushima nuclear accident, almost 60% of the respondents had favorable views of NPPs, approximately 26% of the respondents were against NPPs, and the rest of the respondents were ambivalent. However, the 2011 survey which was conducted after the Fukushima nuclear accident showed that public support for NPPs declined to 49.5%.

Table 6.2 shows the results of the logistic regressions for the public acceptance of NPPs in Indonesia for both the model specifications. The specifications of these models are preferred over others based on the Bayesian information criterion (BIC). The coefficients of the estimates show the effect of the independent variables on two outcome categories relative to being ambivalent, which is selected as the base category. The first outcome category refers to the selection between being in favor of NPPs and being ambivalent, while the second outcome category refers to the selection between opposition to NPPs and being ambivalent. The



Notes: numbers in square brackets show reference number

Figure 6.1 Path model of social acceptance of NPP positive and significant coefficient of the estimates means that people are more likely to be either in favor of NPPs (for columns (2) and (4)) or against NPPs (for columns (3) and (5)) rather than being ambivalent. From Table 6.2, we can see that all the independent variables for both models are found to be significant predictors for the public acceptance of NPPs, as expected. Furthermore, we also find a rather similar interpretation of the estimation results of both models. The Fukushima nuclear accident, proximity to an NPP site, women, age and fear of nuclear weapons are negative predictors of the acceptance of NPPs. Meanwhile, familiarity with NPPs and information on the benefits of nuclear energy are found to be positive predictors of the acceptance of NPPs. Education level has almost an equal impact on both the acceptance and opposition to NPPs. Finally, we find that trust in the managing authorities as a whole is associated with a higher acceptance of NPPs. However, if we segregate trust into each authority, we find various impacts of trust in shaping the acceptance of NPPs, which will be discussed in detail later in this section. The post estimation analysis of our models is given in Table 6.3. From Table 6.3, it can be seen that based on the likelihood-ratio test, all the variables are significant at the 0.05 level. Additionally, the likelihood-ratio test for the outcomes of the dependent variable show that all of the outcome categories are distinguishable and should not be combined.

The coefficients provided in Table 6.2 are in the form of log of odds ratios between the variables and their reference group. To observe the dynamics between the outcomes and to make further interpretation of the models, it is more convenient to analyze the models in the form of a factor change coefficients (odds ratio) plot, as suggested by Long and Freese (2006). This plot enables us to easily recognize the relative influence of the independent variables associated with each outcome and to identify which outcome is more likely to be observed (Long and Freese, 2006). The odds ratio plot for the models of acceptance of NPP is presented in Figure 6.2. The plot contains three markers that represents the three outcomes of the dependent variable. The triangular marker represents acceptance of NPPs, while the X marker and circular marker represent opposition to NPPs and uncertain attitude toward NPPs, respectively.

Table 6.2 Acceptance of NPP from the multinomial logit model

Variables	Model 1		Model 2	
	In Favor vs. Indecisive	Against vs. Indecisive	In Favor vs. Indecisive	Against vs. Indecisive
(1)	(2)	(3)	(4)	(5)
Year2011	-0.58495[a]	-0.09153	-0.52294[a]	-0.07240
NPPSite	-1.32838[a]	-0.01563	-1.35417[a]	-0.01364
Demographic Variables				
Female	-0.44793[a]	-0.17918[b]	-0.43439[a]	-0.16917
Age	-0.13634[a]	-0.08422[b]	-0.13793[a]	-0.08258[b]
Educ	0.11302[a]	0.12225[a]	0.10898[a]	0.11152[a]
Perceived Benefit				
AdvNPP	0.69267[a]	0.15266	0.68648[a]	0.13450
Knowledge & Information				
PubEng	-0.70907[a]	-1.11635[a]	-0.67467[a]	-1.09068[a]
TVCom	0.58884[a]	0.31937[b]	0.57029[a]	0.31280[b]
Adv	0.46460[b]	0.21852	0.44404[b]	0.20296
ElecCri	0.84694[a]	0.56098[a]	0.82989[a]	0.54264[a]
KnowNPP	0.63410[a]	0.15315	0.62077[a]	0.15303
NucWeap	0.49788[a]	0.60574[a]	0.48816[a]	0.58710[a]
Trust				
TrustGen	0.14210[a]	0.05724	-	-
TrustCentGov	-	-	-0.20298[b]	-0.02780
TrustLocGov	-	-	0.30613[a]	-0.05000
TrustBATAN	-	-	0.37482[a]	0.25504[a]
Cons	1.35901[a]	1.05164[a]	1.34824[a]	1.06310[a]
Number of observations	5372		5372	
Pseudo R-squared	0.0893		0.0933	
χ^2	960.11		1004.08	
BIC	10037.652		10028.031	

[a] Significant at 1%

[b] Significant at 5%

The primary objective of this paper is to study the different impacts of trust in the multilevel managing authorities i.e., the central government, nuclear energy authorities and local government, in shaping public acceptance of NPPs. Although trust in the managing authorities as a group leads to a higher probability of acceptance of NPPs, as expected, our findings for segregated trust are very intriguing. First, we find that the effect of trust in the nuclear energy authorities, which is represented by the variable *TrustBATAN*, leads to a higher probability of acceptance of NPPs. Although the coefficients of *TrustBATAN* in Table 6.2 are

Table 6.3 Likelihood-ratio test result

Variables	*Model 1*			*Model 2*		
	χ^2	*df*	*Prob* > χ^2	χ^2	*df*	*Prob* > χ^2
Year2011	35.751	2	0	28.636	2	0
NPPSite	54.576	2	0	57.079	2	0
Female	33.502	2	0	31.606	2	0
Age	18.783	2	0	19.288	2	0
Educ	14.464	2	0.001	12.209	2	0.002
AdvNPP	30.300	2	0	30.821	2	0
PubEng	68.438	2	0	64.922	2	0
TVCom	21.284	2	0	19.636	2	0
Adv	9.966	2	0.007	9.268	2	0.01
ElecCri	87.401	2	0	83.032	2	0
KnowNPP	27.077	2	0	25.483	2	0
NucWeap	20.210	2	0	18.825	2	0
TrustGen	10.286	2	0.006	-	-	-
TrustCentGov	-	-	-	9.919	2	0.007
TrustLocGov	-	-	-	30.642	2	0
TrustBATAN	-	-	-	17.708	2	0
In Favor & Against	344.837	13	0	368.874	15	0
In Favor & Indecisive	502.326	13	0	518.389	15	0
Against & Indecisive	336.024	13	0	342.544	15	0

significant for both outcomes, which imply that trust in the nuclear energy authorities might lead to both acceptance and opposition to NPPs, the odds ratio plot shows that the marginal impact of trust in the managing authority on the acceptance of NPPs is positive. This can be seen from the position of the triangular marker in the plot that lies above the X and the circular marker, suggesting that the likelihood of becoming in favor of NPPs is noticeably higher than becoming either indecisive or against NPPs. This finding is similar to the earlier results of Bronfman et al. (2012), showing that trust in energy authorities is a critical aspect that will increase the acceptability of nuclear energy. Second, trust in the local government is highly associated with a positive attitude toward NPPs. This can be inferred from the coefficient of *TrustLocGov*, which is found to be positive and significant for the first outcome category. Additionally, we find no evidence of a significant correlation between *TrustLocGov* and opposition to NPPs in the second outcome category. From the odds ratio plot, we can see that the triangular marker of *TrustLocGov* convincingly lies above the two other markers, suggesting its significant impact on increasing the chance of becoming a proponent of NPPs. Our result is somewhat similar to the earlier study of Kojo and Richardson (2014) who found a greater preference for involving local actors during the community benefits approach in the siting of nuclear waste management facilities.

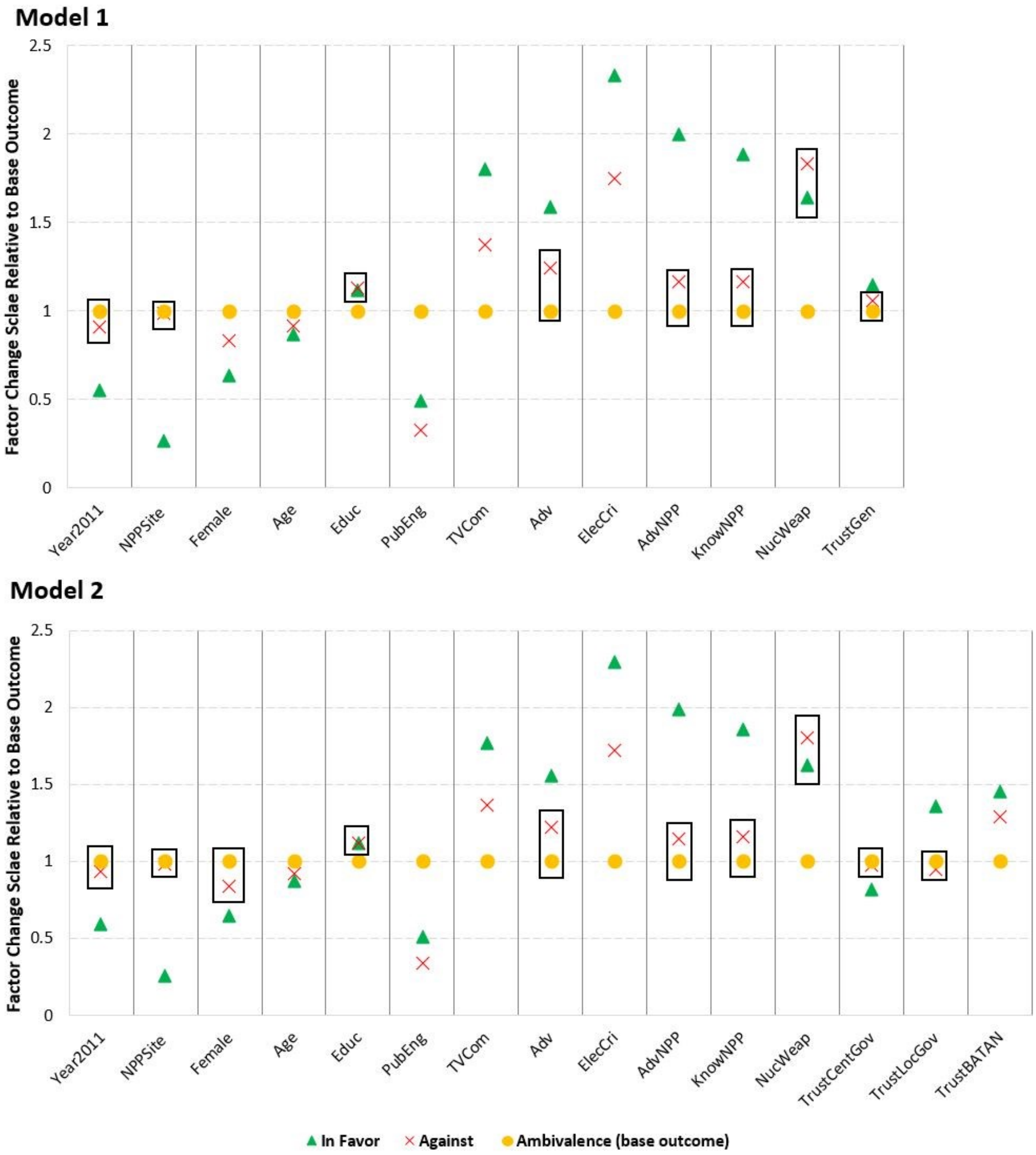


Figure 6.2 Odds ratio plot of acceptance of NPP

Finally, the impact of trust in the central government on the acceptance of NPPs is barely perceptible, since its marginal effect leads to ambivalent attitudes toward NPP. From Table 6.2, we can see that the coefficient of *TrustCentGov* is negative and significant on the first outcome and there is no significant effect of trust in the central government on the second outcome. This finding implies that trust in the central government leads to a higher chance of becoming indecisive about NPPs but is not associated with opposition toward NPPs. This finding is confirmed further from the odds ratio plot of *TrustCentGov*, where the circular marker is positioned slightly above the X marker and considerably higher than the triangular marker. Hence, compared to the other outcomes, ambivalent attitudes toward NPP have the highest probability for being observed. This attitude might be attributed to people's doubts about the strong commitment of the central government to support the NPP project. The long-term commitment of the central government toward the NPP project in Indonesia is reflected in Government Regulation 79/2014 regarding the national energy policy which states that nuclear energy is being considered as a feasible alternative of new and renewable energy sources to be included in the national energy mix, but only as the last option. Nevertheless, this regulation is often interpreted as hesitation instead of a commitment by the central government to NPP projects due to its ambiguous wording. As a result, affective trust in the central government, which is highly influenced by, among other things, the strong commitment of the central government toward NPPs, fails to encourage the acceptance of NPPs. Our finding is similar to that of Kim et al. (2014) who found that trust in the managing authorities is significant for lessening opposition to NPPs, but not truly effective for encouraging people to support NPPs.

Our findings for the other explanatory variables also suggest noteworthy implications. First, the plot of variable *Year2011*, which captures the difference in acceptance patterns before and after the

Fukushima nuclear accident, shows that the position of the triangular marker is below the position of the X marker and the circular marker. Additionally, the plot also shows a rectangle conjoining the X marker and the circular marker. This plot implies that there was a significant change in the acceptance pattern of NPPs after the Fukushima nuclear accident. People were more likely to express an unfavorable attitude toward NPPs, either becoming strongly opposed or being uncertain about their stance on NPPs. Meanwhile, the rectangle that enfolds the X marker and the circular marker indicates that there was no change in the acceptance pattern between those two outcome groups. Interestingly, the chance of being ambivalent was higher than the chance of being an opponent of NPPs. This is indicated by the relative position of the circular marker, which is located slightly above the X marker. Our finding is consistent with that of Bird et al. (2014), Kim et al. (2013) and Kim et al. (2014), showing a declining trend of public support for NPPs after the Fukushima nuclear accident. This finding implies that major nuclear accidents might increase the perceived risks of NPPs, but people responded to this situation differently. Some people who rely on affect heuristics made a quick judgment by immediately shifting their view to oppose NPPs immediately after the Fukushima nuclear accident. However, there was a higher chance for people to keep relying on their knowledge and intellectual judgement to carefully evaluate the risks and benefits of NPP. Hence, as a response to the Fukushima nuclear accident, rather than being an opponent of NPPs, people tended to become indecisive about NPPs. This would buy them some time to reevaluate their judgement about the risks and benefits of NPPs.

Second, proximity to an NPP site, which is represented by the *NPPSite* variable, is found to be a negative and significant predictor of support for NPPs. This can be seen from the triangular marker, which is positioned below the other markers. Additionally, the lowest position of the triangular marker in the plot indicates that proximity to an NPP site has the strongest impact on opposition to an NPP compared to the other negative predictors of NPPs. This finding suggests the existence of the NIMBY effect. Our finding is consistent with that of Van der Horst (2007) and Yuan et al. (2015) who found a positive correlation between the proximity to a site and a less supportive attitude toward energy technology. A similar NIMBY-like attitude for NPPs was also shown by Sun and Zhu (2014) for the case of China which is indicated by the attitude of households that are willing to pay extra money to prevent the construction of an NPP in their vicinity. However, our finding contradicts the earlier result from Cale and Kromer (2015) who found no relationship between geographic proximity and the acceptance of nuclear energy. From the plot of *NPPSite* we can also see that the X marker nearly coincides with the circular marker. This implies that people who reside near the future site of an NPP do not necessarily become opponents of NPPs, but there is also an almost equal chance for them to become indecisive. The uncertain attitudes from local residents imply that they are expecting further justification about the rationale behind a policy before they can make their decisions. This further emphasizes the importance of public engagement in every stage of a nuclear project as a means of two-way communication between local stakeholders and the managing authorities, as suggested by Whitton et al. (2015). However, as we can see from the model, public engagement, which is represented by the *PubEng* variable, has not been very influential in shaping public support for NPPs, which is beyond our expectation. Public engagement is very effective in decreasing the chance of being an opponent of NPPs. However, the beneficial impact of public engagement for increasing the chance of being a supporter of NPPs is rather small because people were likely to be ambivalent.

Third, demographic variables are found to be influential predictors of attitudes toward NPPs. Being a female and being older decrease the possibility of supporting NPP. These findings are indicated by the lower position of the triangular marker on both variables. Our finding is consistent with that of Corner et al. (2011), Ertör-Akyazı et al. (2012), Kim et al. (2013), Kim et al. (2014), Liu et al. (2008), Mah et al. (2014), NEA-OECD (2010), Stoutenborough et al. (2013) and Sundström and McCright (2016), showing that males have a greater tendency to support NPP. Our result is also consistent with a recent study by Arikawa et al. (2014) who found a less supportive attitude toward NPPs from older generations in Japan and Kim et al. (2013), who showed a negative correlation between age and the acceptance of NPPs. Education, on the other hand, shows an interesting impact on attitudes toward NPPs. The plot of the *Educ* variable shows that well-educated people have almost an equal chance of being either a proponent or an opponent of NPPs. However, the impact of education level on those outcome groups is rather small. Additionally, the plot also shows that there is no evidence that a higher education level would cause a sudden change in people's opinions from being a proponent of NPPs to becoming an opponent of NPPs, and vice versa. These findings imply that education is a gradual process that might provide a positive impact on the acceptance of NPPs in the long term. Our finding contradicts the earlier result from Arikawa et al. (2014) and NEA-OECD (2010), finding a positive correlation between the level of education and a supportive attitude toward NPPs.

Fourth, the odds ratio plot shows that mass media campaigns are effective in promoting the acceptance of NPPs. This can be seen from the position of the triangular markers for the *TVCom* and *Adv* variables, which are relatively higher than the others. Additionally, the higher position of the triangular marker for *TVCom* compared to *Adv* indicates that TV commercials are more influential than other types of commercials. However, there is a small chance that TV commercials might also lead to a negative acceptance of NPPs. The different outcomes of TV commercials on attitudes toward NPPs are likely due to the various demographic backgrounds of the audience. Unlike TV commercials, media campaigns through newspaper and the Internet, which have a relatively homogenous audience, always resulted in a positive outcome.

Finally, information about the risks and benefits of NPPs is a significant predictor of attitudes toward NPPs. Information on the benefits of nuclear energy is associated with supportive behavior toward NPPs. This information includes general knowledge of NPPs and the advantages of NPPs over other types of power plants. Additionally, information and experience on current energy situations might increase people's awareness about the threat of electricity crises in the near future, which in turn will act as a driving factor in the acceptance of NPPs. Compared to other factors, concern about energy security has the strongest influence on the acceptance of NPPs. This can be seen from the position of the triangular marker, which is relatively higher compared to the others. Meanwhile, information on the risks of nuclear energy is found to be associated with unsupportive behavior toward NPPs. This information includes knowledge about the possible utilization of nuclear energy for weapons. People who associate nuclear energy with weapons of mass destruction have a greater chance of being an opponent of NPPs. Our finding is consistent with that of Corner et al. (2011), Visschers et al. (2011) and IAEA (2014) who found that acceptance of nuclear energy is driven by people's concerns about energy security and climate change.

We also attempt to further study the interactions between trust and the other explanatory variables in determining the acceptance of NPPs. In doing so, we employ the path model, as shown in Figure 6.1. The results of the GSEM estimation from the path model are provided in Table 6.4. From Table 6.4, we can see that the direct impacts of trust in the public acceptance of NPPs are in good agreement with the previous multinomial logit model for both models. As a whole, the direct marginal effect of trust in the managing authorities is associated with a positive attitude toward NPPs. Shifting to trust in specific authorities, we find that the direct marginal effect of trust in BATAN and local government leads to acceptance of NPPs. Meanwhile, trust in the central government tends to render people indecisive. In addition, Table 6.4 provides additional information about the significant predictors of trust and the indirect effects of trust in the acceptance of NPPs, which is almost similar for both models. The following are the main findings from the path model.

Table 6.4 Acceptance of NPP from the path model

Variables	Model 1		Model 2	
	Coefficient	Std. Error	Coefficient	Std. Error
TrustGen ←				
NPPSite	-1.07214 [a]	0.16424	-	-
Year2011	-0.23945 [b]	0.10680	-	-
PubEng	0.11990	0.11406	-	-
KnowNPP	-0.16559	0.11375	-	-
NucWeap	0.12287	0.09145	-	-
Cons	1.46790 [a]	0.07444	-	-
TrustCentGov ←				
NPPSite	-	-	-0.96519 [a]	0.17342
PubEng	-	-	-0.09665	0.05743
KnowNPP	-	-	-0.40623 [a]	0.08148
Cons	-	-	0.10317 [b]	0.04747
TrustLocGov ←				
NPPSite	-	-	-0.14463	0.16833
PubEng	-	-	0.44152 [a]	0.06207
KnowNPP	-	-	-0.21534 [b]	0.08684
Cons	-	-	-0.91933 [a]	0.05242
TrustBATAN ←				
NPPSite	-	-	-1.02613 [a]	0.17250
Year2011	-	-	-0.75357 [a]	0.08374
PubEng	-	-	-0.58486 [a]	0.09152
KnowNPP	-	-	0.27648 [a]	0.08865
NucWeap	-	-	0.57826 [a]	0.06929
Cons	-	-	0.55713 [a]	0.10530
KnowNPP ←				
PubEng	0.44371 [a]	0.09761	0.44371 [a]	0.09761
TVCom	1.26387 [a]	0.09959	1.26387 [a]	0.09959
Adv	0.81803 [a]	0.11124	0.81803 [a]	0.11124
Educ	0.48722 [a]	0.02610	0.48722 [a]	0.02610
Cons	-4.84137 [a]	0.15115	-4.84137 [a]	0.15115
AdvNPP ←				
TrustGen	0.10462 [b]	0.05375	-	-
TrustCentGov	-	-	0.04064	0.09728
TrustLocGov	-	-	-0.30706 [a]	0.10742
TrustBATAN	-	-	0.60656 [a]	0.10147
ElecCri	0.61071 [a]	0.11624	0.52939 [a]	0.11739
KnowNPP	1.18962 [a]	0.10664	1.12686 [a]	0.10785
Cons	-3.09408 [a]	0.12432	-3.15321 [a]	0.12778

Table 6.5 (continued)

Variables	Model 1		Model 2	
	Coefficient	Std. Error	Coefficient	Std. Error
InFavor NPP ←				
NPPSite	-1.21865 [a]	0.23525	-1.25445 [a]	0.23559
TrustGen	0.13903 [a]	0.04902	-	-
TrustCentGov	-	-	-0.27771 [a]	0.08400
TrustLocGov	-	-	0.25181 [a]	0.08783
TrustBATAN	-	-	0.50563 [a]	0.08755
Year2011	-0.54259 [a]	0.09064	-0.48746 [a]	0.09159
AdvNPP	0.97416 [a]	0.20070	0.94424 [a]	0.20167
Female	-0.54720 [a]	0.08490	-0.52264 [a]	0.08535
Age	-0.18012 [a]	0.03096	-0.18021 [a]	0.03115
Educ	0.22642 [a]	0.03202	0.20845 [a]	0.03263
NucWeap	1.06061 [a]	0.12379	1.01848 [a]	0.12464
Cons	1.21196 [a]	0.22782	1.25511 [a]	0.22939
Against NPP ←				
NPPSite	0.04032	0.20077	0.04075	0.20150
TrustGen	0.05748	0.05080	-	-
TrustCentGov	-	-	-0.08051	0.08699
TrustLocGov	-	-	-0.10196	0.09207
TrustBATAN	-	-	0.36886 [a]	0.09073
Year2011	0.31136 [a]	0.09404	0.32468 [a]	0.09491
AdvNPP	0.32900	0.21202	0.29391	0.21268
Female	-0.23933 [b]	0.08808	-0.22074 [b]	0.08835
Age	-0.13118 [a]	0.03185	-0.12817 [a]	0.03197
Educ	0.19917 [a]	0.03327	0.17688 [a]	0.03385
NucWeap	1.11331 [a]	0.12562	1.07107 [a]	0.12627
Cons	0.27599	0.23799	0.33024	0.23934
Indecisive (base outcome)				
Number of observations	5372		5372	
df	32		47	
BIC	21672.42		38347.69	

[a] Significant at 1%

[b] Significant at 5%

First, a major nuclear accident acts as a negative experience that reduces trust in the nuclear energy authority and the managing authorities as a whole, which in turn leads to less supportive behavior toward the acceptance of NPPs. This can be seen from the negative coefficients of *Year2011* on *TrustBATAN* and *TrustGen*. Second, the proximity to an NPP site significantly reduces both the general trust in the managing authorities and the specific trust in BATAN and the central government. However, it has no effect on trust in the local government. The most likely cause of this finding is the stronger connection between the host community and the local government, which might come from intense communication between them. This is very beneficial not only for building trust but also for resolving conflicts of interest among them. Third, we find that there are different patterns of how trust is built among these three authorities. Trust in BATAN is mostly driven by knowledge about NPPs, but trust in the local government mostly comes from the beneficial outcomes of public engagement. Nevertheless, we find no evidence of a significant driver of trust in the central government. Evaluating the path model further, we also find that trust in BATAN is the only aspect of trust that has a positive impact on the benefit perception of NPPs. These findings imply that in general, knowledge about NPPs is very favorable for creating trust in the nuclear energy authority, which in turn will positively influence the benefit perception of NPPs. However, if there is a lack of sufficient knowledge about NPPs, the acceptance of NPPs is determined by the degree of trust in the local government, disregarding the evaluation of the net benefits or risks that might result from NPPs. Here, we can see the important role of public engagement in promoting the acceptance of NPPs. Although the impact of public engagement on shaping the overall knowledge of NPPs is less powerful compared to other means of public communication and formal education, it is very beneficial for building trust among stakeholders. The purpose of public engagement is more than just exposing the public to information about NPPs, but it is also a means of two-way communication that enables people to express their concerns regarding NPP projects.

6.5 Conclusions and policy implications

This paper aims to study the role of trust in affecting the acceptability of NPPs in Indonesia. Specifically, this paper tries to distinguish the different roles of the multilevel managing authorities in enhancing the public acceptance of NPPs. In addition, this paper also attempts to identify the key factors that determine the public acceptance of NPPs in Indonesia. A total sample of 5,372 respondents from 22 cities in seven major provinces in Indonesia was included.

In summary, our estimates showed that all of the variables are significant predictors of the acceptance of NPPs. Major nuclear accidents and the proximity to the NPP site have a strong and negative influence on the acceptance of NPPs. Demographic variables such as age, sex and education are also found to have a modest effect on the acceptance of NPPs. While age and being female decrease the likelihood of being a supporter of NPPs, the impact of education level is rather interesting since it has almost an equal impact for both endorsing the acceptance and opposition to NPPs. Additionally, familiarity with NPPs has a positive impact on the acceptance of NPPs. For instance, people's knowledge about NPPs and its comparative advantages leads to more support for NPPs. In contrast, negative information about NPPs, such as the association between nuclear energy and weapons of mass destruction, leads to less support for NPPs. Furthermore, supplementary information about the current energy situation is also beneficial for endorsing the acceptance of NPPs since having concerns about future energy security is found to have a very strong influence on the acceptance of NPPs. Moreover, exposing the public to nuclear-related information using mass media campaigns is found to be effective. However, the direct impact of public engagement on the acceptance of NPPs, which is measured by public involvement in nuclear-related dissemination events, is less significant. Finally, trust in general has a positive impact on the acceptance of NPPs, with the exception of trust in the central government, which encourages people to become ambivalent.

From the path model, this paper identifies different patterns of how trust is built among the central government, the nuclear energy authority, and the local government in promoting the acceptance of NPPs. Knowledge about NPP is beneficial for creating higher trust in the nuclear energy authority, which further increases the perceived benefit of NPPs.

Meanwhile, public engagement leads to a higher trust in the local government that directly influences the acceptance of NPPs. With regard to trust in the central government, we find that the role of the central government in promoting the acceptance of NPPs is barely perceptible since it is not associated with either acceptance or opposition to NPPs.

Our findings suggest the different roles of the managing authorities in enhancing the social acceptance of NPPs, which according to Wüstenhagen et al. (2007) comprises three interdependent elements, namely sociopolitical acceptance (which consist of public, stakeholders and policy makers), community acceptance, and market acceptance. First, our findings suggest that community acceptance can be enhanced by allowing a greater involvement of local government in the decision-making process. The local government should be appointed as a hub institution that plays an important role in translating the national energy policy into local wisdom. Additionally, the local government is also expected to be able to engage the public on NPP projects by providing comprehensive information about the rationale behind the policy. This will reduce the communication gap with local stakeholders and ensure both equity and fairness in every stage of the decision-making process. Second, trustworthiness of nuclear energy authorities is associated with the higher public acceptability of NPPs. To become trustworthy, nuclear energy authorities are required to provide comprehensive information about NPP projects covering not only their beneficial impacts but also the possible risks and threats that might result from the project. This information should be available in ways that can be easily comprehended, even by lay people. Additionally, they also need to encourage public participation and to be more receptive not only to experts but also to the opinions of lay people. Finally, although the impact of trust in the central government on the public acceptance of NPPs is barely perceptible, the long-term commitment of the central government is required for creating market and political acceptance of NPPs. For instance, the GoI should consider establishing a Nuclear Energy Program Implementing Organization (NEPIO) to manage the NPP project in Indonesia. Although most of the main tasks of NEPIO have already been handled by BATAN together with other related ministries and agencies, the establishment of NEPIO is very important for showing the government's long-term commitment to NPP project. Third, our findings encourage the necessity of realizing synergy between each management authority and dismiss the possibility of a certain authority to act as a sole key player in NPP-related policies.

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Chapter 7 Conclusion

The impact of energy consumption on sustainable well-being has become the subject of long-running discussion within the policymakers. This paper aimed to contribute to the literature by investigating whether the current pattern of energy consumption is associated with the improvement or deterioration of well-being by using the inclusive wealth (*IW*) index as a proxy. For this purpose, this paper conducted an analysis of global energy consumption pattern which involved more than one hundred countries over a span of more than twenty years. Additionally, this paper also performed a country specific analysis by taking Indonesia as a case study to test the existence of environmental Kuznets curve (EKC) hypothesis and to gain further insight into the challenge of energy-related policy implementation in a developing country.

The main findings from this study are summarized as follows:

- In Chapter 2, this paper aimed to estimate the abundance of global marine fisheries stock by using catch data and found a declining trend of stock as a result of the increasing trend of catch levels worldwide over the last five decades. However, over the next two decades, it was forecasted that there will be indications of stock recovery which was attributed to the peaked catch level.
- Chapter 4 also attempted to discover a connection between the stage of economic development and both the catch level and the abundance of stock. However, this paper fund no evidence of the conventional EKC hypothesis for global marine fisheries from catch and biomass stock models. However, the models show that the beneficial impacts of economic growth on global marine fisheries are likely to be achieved. The catch model reveals the occurrence of a secondary turning point at an income level of 3,827 USD per capita after which further economic growth will lead to a decline in catch levels. In addition, the biomass model presents a secondary turning point

occurring at an income level of 6,066 USD per capita after which further economic growth will lead to stock improvements.

- In Chapter 3, this paper showed a negative and significant impact of energy consumption on per capita *IW* growth, suggesting an unsustainable pattern of world energy consumption, since higher energy consumption leads to lower growth of per capita *IW* and vice versa. However, economic growth was found to have a significant and favorable impact on the sustainability of economic development by promoting per capita *IW* growth.
- Additionally, from the non-parametric models, this paper forecasted that over the next three decades, the average growth of per capita *IW* should increase alongside economic growth and the number of countries that should follow a sustainable development path would likely increase in the future. However, the growth of per capita *IW* will be hindered by increasing levels of energy consumption and population growth.
- In Chapter 4, this paper also found evidence of a promising sustainable future for three different energy pathways which was indicated by a steady increasing average per capita *IW*. Hence, CO_2 emissions mitigation scenarios can be implemented with no adverse effects on the sustainability of well-being.
- However, this paper found different impacts of each energy pathway on future well-being. The highest gain in average per capita *IW* was associated with mix scenario, while efficiency scenario led to the lowest growth in CO_2 emissions. However, the impacts of those energy pathways on well-being in the medium term differed significantly from the long term.
- This paper also showed that the growth patterns of average per capita *IW* differed widely between income groups of which high income group has a greater tendency to follow the sustainable development path.

- In Chapter 5, this paper aimed to estimate the EKC for the case of Indonesia by considering electricity production from renewable energy sources for the period of 1971-2010 and found a strong evidence that support the existence of EKC hypothesis.
- However, the estimated turning point was found outside the sample period, i.e. around 7,729 USD per capita. The relatively huge gap between current economic level and the estimated turning point suggest that the Government of Indonesia (GoI) should evaluate the efficacy of current energy and environmental policies to obtain an EKC that is lower and flatter than the estimated turning point would suggest.
- Chapter 5 also showed the favorable impact of renewable energy sources on CO_2 emissions reduction both in the short run and in the long run. However, it also sounded a warning about the increasing inefficiency of energy consumption in the long-run
- In Chapter 6, this paper aimed to distinguish the different roles of the multilevel managing authorities in enhancing the public acceptance of a new energy technology by taking the first nuclear power plant (NPP) project in Indonesia as a case study. This paper found that trust in general had a positive impact on the acceptance of NPPs. Nuclear energy authorities played an important role in promoting the public acceptance of NPPs while a local government’s role was essential for encouraging the acceptance by a local community. Trust in the central government, on the other hand, was unfavorable for both the acceptance of and opposition to NPPs