Assessing the feasibility of energy transitions in Indonesia to reduce both air pollution and GHG emission

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Abstract

The Indonesian energy system is a substantial contributor to both air pollution and greenhouse gas (GHG) emissions. Emissions of air pollutants can cause high levels of particulate matter (PM) pollution that is damaging to human health whilst emissions of GHGs have resulted in Indonesia being a substantial contributor to global GHG emissions leading to global heating as well as leading to regional climate change. GHGs and air pollutants are often co-emitted from the same sources and the energy sector in Indonesia contributes approximately 61% and 67% to these emissions respectively.

A number of energy scenarios, designed to transition to the use of more sustainable energy systems, have been developed by the Indonesian government as well as other regional and international organisations. These scenarios focus on GHG emission reductions (ignoring the implications of shifts in energy use and supply for air pollution emissions) and exclude considerations of the actual feasibility of the energy transitions identified (both in terms of practical (e.g. cost, technology) as well as physical (e.g. geographical suitability) of the energy transitions proposed.

This study explores these issues by developing an updated GHG and air pollution emission inventory for Indonesia. This allows the emissions from the energy sector to be estimated and placed in context of all Indonesian emissions contributing to air pollution and GHG emissions. The study then assesses the feasibility of potential energy transitions to cleaner or renewable forms of energy provision. This is achieved firstly by consultation with Indonesian energy stakeholders to assess the feasibility of proposed energy transitions to 2030 and secondly, using ‘energy geography’ theory to assess the feasibility of the proposed types of energy provision across Indonesia’s islands. This analysis is used to develop realistic energy transition scenarios that are investigated to assess their benefit to human health and global mean temperature.

The study finds that the proposed energy scenarios substantially improve human health and reduce Indonesia’s impact on global mean temperature. The ‘maximum feasible renewable (MFR)’, ‘clean energy (such as Liquefied petroleum gas (LPG) and Compressed Natural Gas (CNG))’ and ‘renewable energy’ scenario resulted in the avoidance of premature mortality by 134,000, 23,000, and 31,000 people respectively. The ‘maximum renewable energy’ transition can be achieved by considering island’s energy sources. Based on the National Energy Policy of 2006 Indonesia plan to reach target total primary energy supply of 400 million tonnes of oil equivalent and 25% of renewable energy in the energy mix by 2030. The results from this thesis find that maximum benefit from energy future transitions would be achieved by considering both of GHGs and air pollution in energy related emission reduction policy.

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List of abbreviations

CPL	Crop Production Loss
CMM	Coal Mine Mouth
CSA	Indonesia Central Bureau of Statistics
CPO	Crude Palm Oil (CPO)
CNG	Compressed Natural Gas
DEN	Dewan Energi Nasional

GAP	Forum Global Atmospheric Pollution Forum
GFED	Global Fire Emission Database
GHG	Greenhouse Gas
GBD	Global Burden Disease
IEA	International Energy Agency
IER	Integrated Exposure–Response
IPP	Independent Power Producers
INAGA	Indonesia Geothermal Association
INS	Indonesia National Statistics Agency
LEAP-IBC	Long-range Energy Alternatives Planning system - Integrated Benefits Calculator
LPG	Liquefied petroleum gas
LED	Low Emission Development
MFRE	Maximum Feasible Renewable Energy
MLP	Multi Level Perspectives
MOEMR	Ministry of Energy and Mineral Resources
MTOE	Million Tonnes of Oil Equivalent
NUG	Non-utility Generating Companies
PLN	Perusahaan Listrik Negara
PPP	Private Power Utilities
PPA	Power purchase agreement
RYL	Relative Yield Loss
TIS	Technology Innovation System
TPES	Total Primary Energy Supply
SOE	State own Enterprise
UKP4	Unit Kerja Presiden Bidang Pengawasan dan Pengendalian Pembangunan (Presidential Delivery Unit for Development Monitoring and Oversight)
WEM	World Energy Model
WEO	World Energy Outlook

Notes

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Declaration

I declare that the research described in this thesis is original work, which I undertook at the University of York during 2015 - 2019. Except where stated, all of the work contained within this thesis represents the original contribution of the author.

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Notes:

Chapter 1 Introduction

1.1. Indonesia context

Indonesia is the fourth largest country in the world, with a population at 260 million. Indonesia consists of more than 17,000 islands located across the equator as shown in Figure 1-1. Indonesia is an archipelago country in South East Asia located where several tectonic plates meet. This causes one of the most seismically active areas in the world with powerful eruptions and earthquakes frequently occurring.

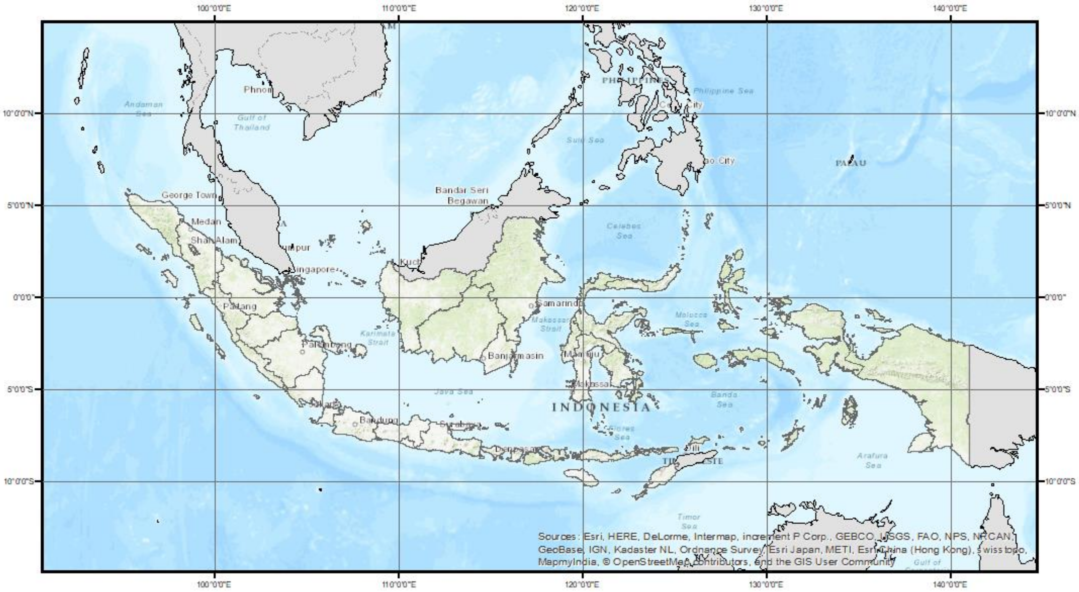

Figure 1-1 Map of Indonesia (Arcgis, 2020)

The influence of this volcanic arc across Indonesia is illustrated by 117 active volcanoes that represent 40% of the world's geothermal energy potential (Nasruddin et al., 2016). Rich oil and gas deposits are found in the Sumatra and Kalimantan islands and their continental shelf.

Indonesia's climate is almost entirely tropical, dominated by the tropical rainforest climate found in every major island of Indonesia, this means the lands are suitable for plantation of energy crops (Ref). The more than 17,000 islands that comprise Indonesia have particular geographical landscapes such as mountains, rivers, and proximity to the sea. This geography is a major factor in energy development since it determines the ease within which different islands can be supplied by the various modes of energy provision and associated energy infrastructure (e.g. roads, rail, electricity grids, off-grid energy supply etc…) and hence is an important consideration in energy policy.

Indonesia is the largest coal exporter and seventh largest liquefied natural gas exporter (IEA, 2014b). Indonesia was also formerly a petroleum exporter, but due to a decline in production and an increase in energy consumption, it has become a net oil importer since 2004. Although fossil fuel has played a key role in the energy and economic development of Indonesia there are a number of problems associated with poor governance and corruption that have hindered the growth of fossil fuel related energy development in Indonesia (Sovacool, 2010).

In spite of this oil and gas still have an important role in the economy, and the state contribution from the energy sector has risen from 26% in 1969 to a peak of 71% in 1982 (Garnaut, 2015). Although currently in decline, the oil and gas sector is still a significant contributor to state revenue with 21-30% of revenues estimated as coming from the oil and gas sectors. State-owned enterprises also play a significant role in the Indonesian economy through enterprises associated with energy, electricity, and transportation. Most of the public sector services such as transportation, energy, and electricity are owned by the government. Critics suggest this situation is causing slow progress in the development of energy systems which combined with a lack of governance has lead to corruption in various economic sectors (Lim and Stern, 2002). There are 141 state-owned company in various sectors in Indonesia.

In the past, the main exports commodities in Indonesia were crude oil and wood which accounted for 18% and 10% of exports respectively in 1995. By 2015, the biggest export of Indonesia came from palm oil which accounted for 10% followed by coal for 9.9% (World Bank, 2014).

Indonesia is dependent on imported oil products. As of 2015, Indonesian oil consumption was 1-million-barrels of oil per day (bopd). The imports of oil products are estimated to be 200,000 bopd or around 40% of total oil consumption. At the same time, Indonesia is exporting around 200,000 bopd or around 20% of domestic oil supply, this situation occurs due to insufficient domestic oil refinery capacity. The transportation sector remains heavily dependent on oil at 83% despite the abundance of gas, of which 59% is exported (ADB, 2016). This is due to the fact that the energy transition to using gas in the transportation sector (i.e. compressed natural gas (CNG) in vehicles) which was implemented in the 1980s, has not yet been successful.

These more recent trends in import and export of energy relevant commodities can be compared with the last 150 years of energy consumption where more than 90% of Indonesia's energy supply has been met by fossil fuels (i.e. coal, oil and gas) (see Figure 1-2). Looking forwards, there are several options for future energy provision for Indonesia, which can be summarised as either focusing on clean (i.e. through the transition to gas) or renewable energy (e.g. solar, wind or geothermal energy).

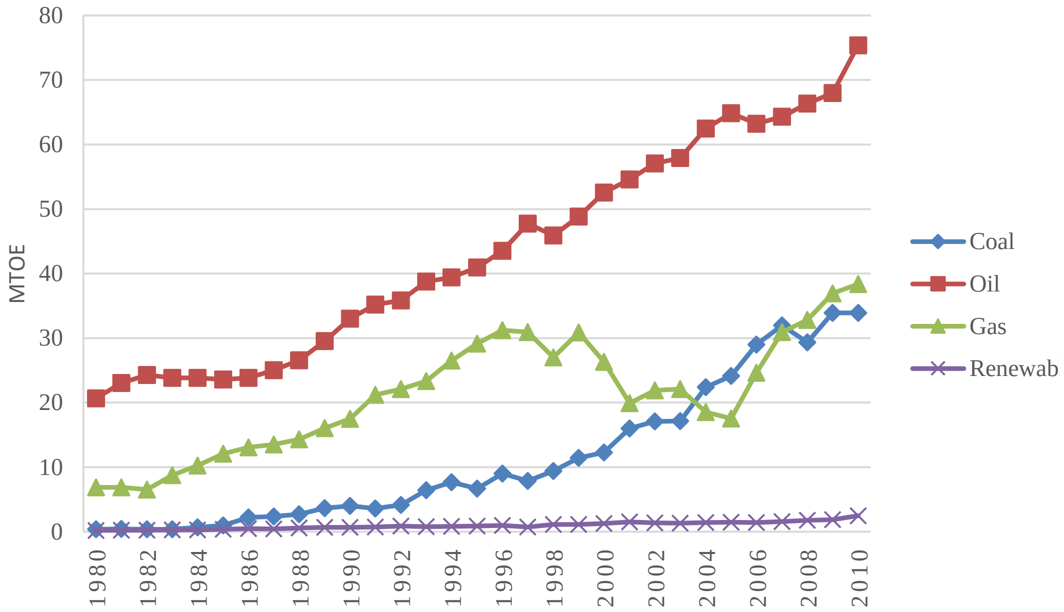

Figure 1-2 Historical energy consumption in Indonesia (IEA 2018)

1.2. Air pollution and greenhouse gases in Indonesia

Energy development is changing the way we produce, distribute and consume energy, it affects all aspects of human life. To understand the impact of energy development is a multidisciplinary effort, which requires the balancing of the negative environmental consequences of energy development with the sometimes conflicting objectives of economicand social development (Dovì and Battaglini, 2015). In Indonesia, energy production and consumption have often caused a significant impact on human health and crop productivity (Shindell et al., 2012).

To understand the environmental impact of energy development we need to understand the current level of air pollution and greenhouse gases that are emitted from of our energy systems and how these relate to atmospheric pollutant concentrations. In Indonesia, data from 2006 to 2012 for 33 provincial capital cities showed a rising trend in air pollution concentrations. NO_2 increased in areas with dense populations, while SO_2 concentrations increased more rapidly in industrial areas (MOEF, 2012). The growth of air pollution in Indonesia has exceeded the rate of economic growth

One of the critical air pollutants is particulate matter (PM) because of the health implications associated with exposure to $PM_{2.5}$ along with its complexity in physical properties and chemical composition (Rashid et al., 2014). For example, a study in 2011 in Jakarta indicated that the $PM_{2.5}$ concentration for industrial sites ranged from 15 - 42 μg/m^3 while at residential ranged from 9 - 36 μg/m^3. The source apportionment of fine particulate matter in the residential area identified the following contributors to $PM_{2.5}$ pollution: lead industry mixed with road dust (12%), diesel vehicles (30%), oil and coal-fired power plant (26%), road dust (17%) and biomass burning mixed with road dust (15%) (Santoso et al., 2011). A study in 2014 in Makassar, South Sulawesi indicated that the average PM_{10} concentration was 32.9 μg/ m^3. The concentration of PM_{10} found in this study was lower than those measured in more developed cities like Bandung 61.0 μg/ m^3 and Serpong 51.8 μg/ m^3 (Rashid et al., 2014). Indonesian authorities are becoming concerned about the public health implications of PM and have recently started monitoring in several Indonesian cities (Santoso et al., 2013).

Air pollution in Indonesia impacts human health through inflammation of the respiratory tract; such health outcomes have been directly linked to air quality (Duki et al., 2003; Ostro, 1994). For example, a study in 2014 in Central Java indicated that indoor $PM_{2.5}$ concentrations in the kitchens of dwellings in the mountainous regions of the island were two times higher than in the coastal area. The study also argued that the use of cleaner fuels such as subsidized LPG should be promoted (Huboyo et al., 2014). A study in 1997 of the Indonesian forest fires estimated that between 0.81 and 2.57 Gt of carbon were released (Page et al., 2002) and resulted in PM concentrations of 1,864 μg/m^3 (Kunii et al., 2002) with estimated 15,600 child, infant and fetal deaths (Jayachandran, 2009).

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In term of GHGs, studies indicate that GHG emissions will grow most rapidly in Asia including Indonesia (van Ruijven et al., 2012). One of the drivers causing rapid growth in GHG is the change in consumption per capita and the growth of population (Arto and Dietzenbacher, 2014). For example, by the end of 2022 compared to 1990 levels, the emission of CO_2, $NO_{2,}$ and CH_4 is projected to have increased by 731%, 664%, and 497%, while the economic output of growth is projected to have changed only by 263% (Gumilang et al., 2011). .Indonesia plans to reduce emissions by up to 26% equivalent to about 0.76 gigatons (Gt) CO_2e by 2020 from 1990 levels (Amheka and Higano, 2015).

Various mitigation scenarios for GHGs in Indonesia have been developed with an emphasis on emissions from the agriculture and forestry sectors (Hasegawa and Matsuoka, 2012), (Kaku, 2011), (Boer, 2001) although the urban sector also has been identified as a major source of emissions (Gouldson et al., 2015). The trend of GHG emission in Indonesia can be described in Figure 1-3 below; This shows the significant growth of GHG emissions with the expansion of coal-based energy.

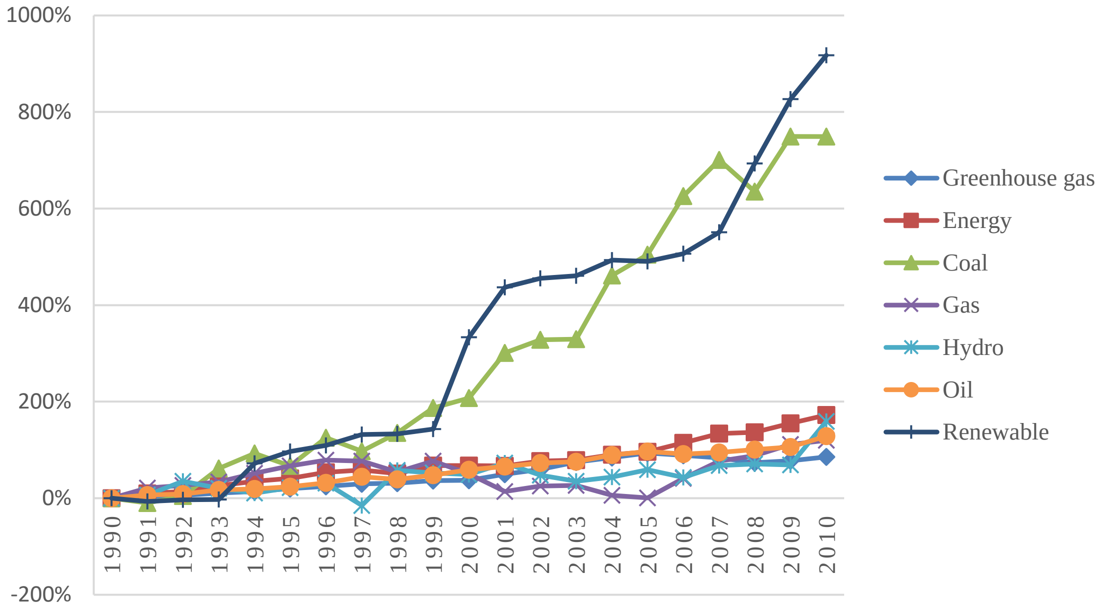

Figure 1-3 Energy consumption and greenhouse gas growth in Indonesia relative to 1990 levels

1.3. Key emission sectors

Energy demand is rising rapidly in Indonesia. The residential sector is the biggest consumer of energy accounting for 37% of energy use, followed by industry at 30% and transportation at 27%. However, in terms of growth, the transportation sector has seen the biggest growth with an annual growth of 7.1% compared with the household sector which only has an annual growth of 0.98% where rapid urbanization is one of the significant factors that contribute to the growth in energy demand (Jupesta, 2010). From the sectoral perspective, electricity, manufacturing and the transportation sectors are the biggest contributors to the GHG emissions and have the highest growth as shown in Figure 1-4.

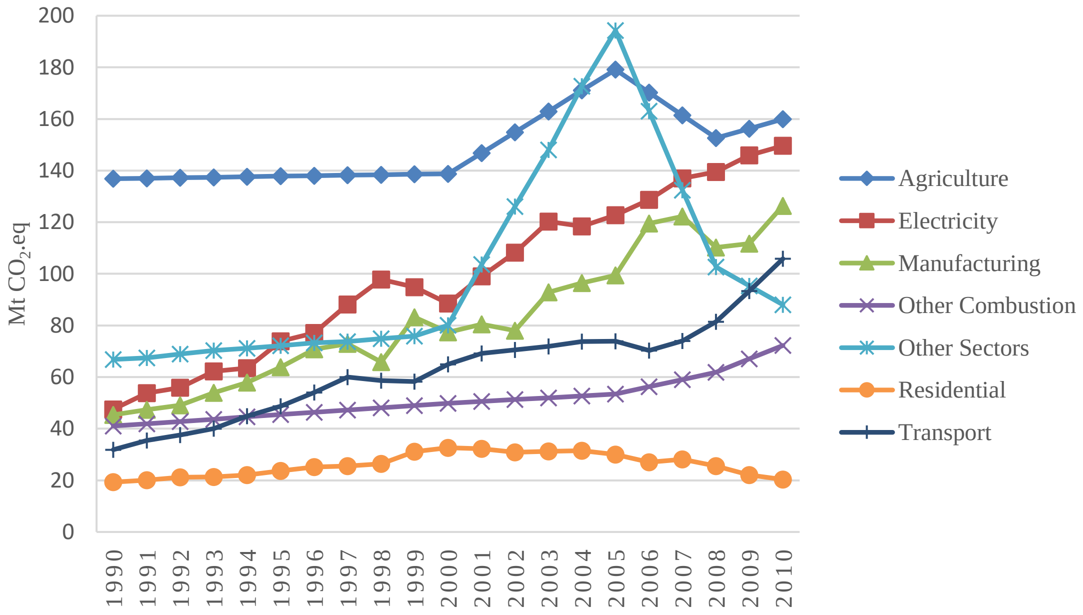

Figure 1-4 Greenhouse gas by sectors in Mt CO_2.eq

Urbanization also leads to an increase in energy demand, with urban areas drawing resources from rural areas and increasing energy use in the transportation sector (York, 2007). In Indonesia, 53% of the population lives in an urban area where the urbanization rate is 4.1% faster than other Asian countries (World Bank, 2016a). Details of emissions from these key sectors in Indonesia are described in the followingsection.

1.3.1. Transportation sector

In Indonesia, passenger cars are the second biggest fuel consumer in the transportation sector. Like many other developing countries, Indonesia has experienced a dramatic increase in the number of passenger cars. The number of passenger cars has increased from 1,170,103 in 1987 to 9,859,926 in 2008 and is expected to reach 38,869,926 in the year 2030 (Ref). This increase in the number of cars will have an impact on fuel consumption and associated emissions (Atabani et al., 2012). Current Indonesian emission standards are equivalent to Euro II and were implemented in 2006. Indonesia expects to advance to Euro IV-equivalent emission standards by 2012 and is also working on plans to upgrade refineries to produce fuels of Euro IV standards (Atabani et al., 2012).

In Indonesia, transportation to connect the islands of the region is extremely important. The Jawa and Sumatra islands have a land-based transportation system, while other islands rely on poorly maintained road networks and shipping to access main population centers (ADB, 2016). In Java and selected parts of Sumatra, particularly in the larger urban areas, roads are highly congested, leading to high social and environmental costs and a drag on economic growth. Rail services are only available in Jawa (which are mainly for passenger transport) and in Sumatra (mainly for the transport of coal). Inter-island shipping is costly because of the small vessel sizes and inefficient operations where most of the ferry services and many of the freight services to the eastern Indonesian islands are supported by a public service obligations (ADB, 2016).

Road transport in Indonesia is characterized by traffic jams which are cuased by a combination of high population, lack of mass transport, and various fiscal initiatives such as fuel subsidies (Burke et al., 2017). Public transportation is not utilized and there is dissatisfaction among customers due to a number factors such as vehicle cleanliness, driver skills, on-time performance, users' security and safety, and inconsistent fares (Joewono et al., 2016). The first regulation to manage transportation to prevent air and noise pollution was the ‘Road Traffic and Transport Law No 14 Year 1992’. This law states that all motor vehicles must meet emission and noise standards. This regulation was later updated in Law No 22 Year 2009 which states that the responsibility for enforcing the law is changed from the Ministry of Environment to the

Ministry of Transportation. According to other regulations, all new vehicles in Indonesia must comply with Euro II standard started from January 2005 (Atabani et al., 2012).

In the transportation sector, there are several policies that have been developed in the past to boost the clean energy transition such as Liquefied petroleum gas (LPG) and Compressed Natural Gas (CNG) conversion in cars and other road-based transportation; fuel economy standards; and the introduction of hybrid vehicles. One of the successful cases of LPG conversion in the transportation sector is the conversion from gasoline to LPG in auto-rickshaws. Auto-rickshaws (also known as Bajaj) provides cheap public transportation. A study indicated that for LPG conversion the importance of infrastructure construction such as the number and distance of refueling stations are highly important for penetrating the market in vehicle switching fuels program. (Destyanto et al., 2017).

CNG conversion has also been successfully implemented across much of the Indonesian taxi fleet. CNG conversion in taxis has been more successful than in private cars (Ref). Many Indonesians are reluctant to switch from gasoline or diesel fuels to CNG largely due to the perceived lack of safety of CNG (Deendarlianto et al., 2017). Fuel economy standards are one of the policies that are expected to be implemented in the future. Fuel economy standards for passenger cars are a relatively cheap measure to influence consumers and to induce market information by encouraging car manufacturers to produce more efficient cars. Due to the increasing number of passenger cars in Indonesia, fuel consumption and therefore emissions will grow rapidly in the future unless a well-planned strategy is adopted by the government. Therefore to reduce this increasing consumption, fuel economy standards for passenger cars have been identified as an important policy initiative (Atabani et al., 2012).

The electric vehicle is one of the transportation sector initiatives that can be used to reduce urban pollution especially when the electric vehicle is expected to reach cost parity with their non-electric counterparts by 2018 (Watts et al., 2018). However, in Indonesia the market share of the electric car is very low, even the hybrid car that combines gasoline and electric is less than 0.58% of the market share. To increase the uptake of hybrid cars there have been a number of initiatives that try to make hybrid car prices mode competitive such as restricting the age limit of cars. Such government interventions could increase consumer's willingness to switch to hybrid vehicles (Irawan et al., 2017).

In Indonesia, designing and implementing transportation regulation requires careful consideration of the constraints and limitations of the current transport system. A study indicated that successful regulations required careful consideration of priorities and objectives, and to anticipate future consequences in implementation and sustainability (Joewono et al., 2016). Moreover, integrated impact assessment, especially on health, is important to analyze and communicate the potential health-related outcomes of transportation policies (McAndrews and Deakin, 2018).

1.3.2. Industry sector

Industry plays important roles in Indonesia economy. In 2013 the contribution of manufacturing industry is 24% of GDP and growing at 5.6%. The mining industry also important contributing to 11% of GDP. Therefore, the energy policies and industrial policies in Indonesia are directly related. Understanding the interconnection of energy and industry policy is important to address the underlying causes of environmental problems (Schaffartzik et al., 2017). Further, energy conservation in the industry sector by improving energy efficiency is a key aspect of achieving efficient energy and industry policy which should include the security of supply, environmental protection, and economic growth (Vivadinar et al., 2016).

The cement industry is the biggest subsector in manufacture industry that consumed energy. Coal supply almost 90% of energy in the cement industry (Vivadinar et al., 2016). The cement is an energy-intensive industry with energy consumption accounting for 30–40% of the production costs. The Indonesian government and cement industry aware of this reliance of coal as a primary energy source, and a major source of pollutant wherein 2005 over 8 million of the industry's almost 12 million tons of CO_2 emissions came from coal (MOEMR, 2017).

Therefore, energy efficiency cement industry is a very important agenda. The number of actions is taken such as to ensure the optimum use of energy in the industry; reduction of energy cost per unit of product output; reduction of environmental pollution generated from industries (Rasul et al., 2005). The government has a plan to improve energy efficiency in the cement industry by performing activities such as shifting to blended cement; using alternative fuels and recovering heat to co-generate electricity. However, the concrete programs in either government or the private sector to save energy in cement is difficult to be established (Rock, 2012).

Pulp and paper industry are the one of manufacture subsector that consumed most energy after cement. 60% of energy supply in the pulp is coming from coal. The pulp and paper sector need to be prioritized due to its extensive energy demand and environmental impacts such as air pollutants, waste treatment and cleaner production (Wang et al., 2016). In Indonesia, pulp and paper industry are at the growth stage because of population, urbanization and GDP growth and urbanization. However, in term of per capita consumption paper consumption is still very low at 17 kg per capita compared with consumption in a developed country at 300 kg per capita (Chen et al., 2012).

1.3.3. Electricity generation sector

Electricity generation is dominated by PLN (Perusahaan Listrik Negara) a state own enterprise (SOE) who own more than 70% of the electricity generation, the rest is with Independent Power Producers (IPP) and Private Power Utilities (PPUs). There are eight electricity transmission networks in Indonesia which have around 39,395 km long transmission grids and around 798,944 km long distribution lines. These distribution lines are not sufficient where a transmission line bottleneck is a recurring problem. A plan to have an additional 220,000 km long distribution line is expected to be developed in 2022 (MOEMR, 2017). For electricity generation, Indonesia has a total installed electricity capacity of 46,400 MW in 2013. However, the electrification ratio is just 80% where the biggest challenge is for rural electrification, and most of the off-grid areas are located far from fuel sources.

PLN (Perusahaan Listrik Negara) is a state-owned company that responsible for around 80% electricity provider in Indonesia. In the past, PLN has a single monopoly on electricity generation and distribution. In 2001 due to the new energy law, a private company can provide electricity in Indonesia. Attracting private sector to involve in Indonesia is difficult because electricity is heavily subsidized. In a lot of cases, the price of electricity generation is higher than the price that paid by the customer. Electricity price is also regulated at the national level. In Indonesia, there is no single integrated electricity grid. The only integrated electricity grid that available is in Jawa and Sumatra island, most of the island is not connected. There is a number isolated grid which uses local energy resources, this geographical condition leads to the development of decentralized power generation (Boedoyo and Sugiyono, 2010).

As a state-owned company, the responsibility of providing electricity was given from governments however the problem is there is no sufficient resources and funding given to PLN to fulfill this mandate (Wu and Sulistiyanto, 2006). As a business within the internal PLN corporation, there is a number problem such as tariff, debt restructuring and renegotiation of Independent Power Producers (Nugroho et al., 2005).

In the operation, PLN operates inefficiently which indicated by a number of technical and non-technical loss in its operation. The technical loss is representing losses that are inherent in the physical delivery of electric energy such as conductor loss, transformer core loss, and coils in metering equipment. Non-Technical Loss representing a loss that not related to the physical characteristics and functions of the electrical network, and is caused primarily by human error, whether intentional or not such as lost due to pilferage, tampering of meters, and erroneous meter reading and/or billing. (Millard and Emmerton, 2009). Moreover, many PLN outages were not from inadequate capacity, but from breakdowns and poor maintenance (Wu and Sulistiyanto, 2006). The loss from electricity theft is quite high because of the poor economic condition. PLN does not connect rural and poor customer until there is sufficient economic strength to ensure that customers can meet the tariff (Millard and Emmerton, 2009).

In the electricity business model, there are three market model that usually used which are Vertically Integrated Utility, Single Buyer Model and Wholesale Competition Model. In the Integrated model, electricity company owns generation, transmission and distribution networks, and sells electricity to consumers. In the Single Buyer, the suppliers buy electricity from non-utility generating companies (NUGs) or independent power producers (IPPs) under long term power purchase agreement (PPA). The electricity supplier has a monopoly to sell electricity. In the Wholesale model, electricity generators and distribution compete in selling their electricity directly to the customer.

Currently, the market model used in Indonesia is the single buyer model. PLN buys electricity from independent power producers under long term contracts. PLN has set up two wholly owned generating companies as subsidiaries. The points of contact for the customers of PLN are the distribution divisions, even for very high voltage customers who are connected at the transmission level. The tariff and quality of service are regulated by the government, while the terms and conditions of customer connection are regulated by PLN itself (Ozveren et al., 2008).

PLN is operating inefficiently for decades, as electricity was subsidized heavily by the government and electricity price at the consumer level is lower than the production costs. This makes the electricity development in Indonesia become slow and face a bureaucratic and corruption problem. Therefore an effort to perform market reform market reform and liberalization has been introduced almost 20 years since the first energy law but substantial changes are difficult to be made due to the scale of geographical position and economic problem (Pintz and Korn, 2005).

Indonesia electricity market liberalization can be analyzed in this aspect which are privatization; wholesale competition; retail competition; unbundling; introduction of independent regulation (Nikomborirak and Manachotphong, 2007). This is gradually implemented based on Electricity Law 20/2002 and revised based on a judicial review by the constitutional court in Electricity Law 30/2009.

In Indonesia, electricity privatization can be in the form of IPP or privatization of state-owned enterprise. The privatization of PLN has been put in the campaign since the market reform along with privatization of several Indonesian companies due to the monetary crisis of 1997 however the privatization is not a popular choice and the public is not agreed with privatization which leads to the amendment of electricity law in 2009 that limit the electricity market reform. The amendment of electricity law limiting the electricity in the electricity unbundling which revise the roles of PLN in the electricity sector–generation, transmission, distribution, and retail sector.

However, in the case of IPP. The IPP has been introduced since the early 1990s however the majority of contract seems not transparent. Between 1994 and 1997, around 25 IPP contracts were granted, and in 2002, about 8.6 percent of electricity is produced by IPPs (Nikomborirak and Manachotphong, 2007). As of 2018 Indonesia electricity industry can be characterized as a partially deregulated. The government through PLN still manage electricity supply and control the tariff for domestic and private companies, the electricity transmission infrastructure is owned by PLN (Sugianto, 2014). In the future, an agenda to fully perform market reform and tariff adjustment should be the priority for PLN.

PLN also increase the capacity of renewable energy such as geothermal. Some of the geothermal power plant has been constructed as a pilot or as small scale power plant in the early 1990s (Radja and Saragih, 1995). Currently, some of the regulation that becomes a barrier for geothermal electricity has been removed. For example, in the geothermal energy, in the past geothermal energy is classified as a mining operation. However with the development of new geothermal policy such as Law No. 21 of 2014 state that geothermal power generation is no longer classed as a mining operation that can be built in a conservation area (Pambudi, 2018). The careful analysis should be performed to design electricity market in Indonesia to be effective, reliable and sustainable. A sufficient supply capacity accompanied by transmission adequacy and reliability of supply must be available in the region to balance between energy access and energy availability (Sugianto, 2014).

1.4. Key consideration for a sustainable energy system in Indonesia

In Indonesia the importance to achieve sustainable energy development can be seen by many efforts of the government in term of energy policy or initiative such as renewable energy development or low carbon development. In this case, sustainability can be defined as patterns of economic, environmental, and social progress that meet the needs of the present day without reducing the capacity to meet future needs. Sustainable energy refers to those patterns of energy production and use that can support society’s present and future needs with the least life-cycle economic, environmental, and social costs (Randolph and Masters, 2008).

In 1987, the Brundtland Commission's Report provided four key elements of sustainable energy: sufficient growth of energy supplies to meet human needs (including accommodating relatively rapid growth in developing countries); energy efficiency and conservation measures, in order to minimize waste of primary resources; addressing public health and safety issues where they arise in the use of energy resources; and protection of the biosphere and prevention of more localized forms of pollution (Jefferson, 2006).

As of low carbon development, according to UN, the concept of low carbon development has its roots in the UNFCCC adopted in Rio in 1992. In the context of this convention, low carbon development is now generally expressed using the term low-emission development strategies or also known as low-carbon development strategies, or low-carbon growth plans (Vera and Langlois, 2007). Though no formally agreed definition exists, low carbon development are generally used to describe forward-looking national economic development plans or strategies that encompass low-emission and/or climate-resilient economic growth (UN-DESA, 2018). To achieve sustainable energy development there are some key challenges such as geographical and technology that need to be consider that have and continue exist for Indonesian energy systems such as environment, socio-technical considerations, energy access and political economy that will be described below.

1.4.1. Environment

The environmental impact of energy development in Indonesia can be explained in term of air pollution and GHG emissions which both have significant impact in Indonesia. Air pollution for example, is one of the major energy related problems in developing countries. Air pollution can benefit from development of energy that have impact on energy system such as combined with climate policy or if renewable energy is promoted.

The current energy system of Indonesia is thought to adversely contribute to air pollution and associated serious health risks such as exacerbated respiratory problems (Bruce et al., 2000; Ezzati and Kammen, 2002; Huboyo et al., 2014). For example, the World Health Organization estimated that over 164,314 deaths per year were attributable to indoor air pollution in 2012 in Indonesia (WHO, 2015). As discussed earlier, the current energy system is causing issues in relation environmental sustainability and particularly in relation to be a primary cause of air pollution with impacts o human health, vegetation and regional climate change.

There is limited energy transition studies in Indonesia that focus on shifting to clean and renewable energy and further quantitative impact measurement in terms of GHG emissions (Tanoto and Wijaya, 2011), (Kusumadewi and Limmeechokchai, 2015) (Rachmatullah et al., 2007). Tanoto and Wijaya (2011) indicated that the increase of geothermal energy in power generation sector from 4% to 10% of the energy mix share will reduce the 43 million tons of CO_2 or 8% in 2027. Kusumadewi and Limmeechokchai (2015) indicated that the use of renewable energy in residential sector will reduce 16% or 159 million tons of CO_2 in 2050. Rachmatullah et al (2007) indicated that the use of gas energy in power generation would reduce CO_2 emission by 15% or 230 million ton by 2020. However, none of the literature described the impact of energy development in terms of integrated GHG and air pollutions in Indonesia.

Studies indicate that the root cause of unsustainable development can be attributed to rapid high energy consumption in unplanned areas (Permana et al., 2008). Unsustainable development also can be attributed to ineffective energy and environment policy, which contradict each other or weak in the implementation (Mujiyanto and Tiess, 2013) (Hasan et al., 2012). The challenge of energy development in Indonesia on the certain characteristics that are specific to developing countries (Pandey, 2002). Study also indicated that the emission reduction can be achieved by various options from energy efficiency to renewable energy which depending on the current energy system, availability of resources and geographic regions (van Ruijven et al., 2012).

1.4.2. Socio-technical

Socio-technical is an interaction between society and technology. Understanding socio-technical aspect provides useful way for sustainable energy (Lawhon and Murphy, 2012). As for Indonesia, energy system is very complex affecting the economy, social, political and technological aspect. Energy is important for the Indonesian economy, 15% of Indonesian GDP comes from energy sector. In terms of tax contribution, 10% of state income is from energy related tax (Boyd et al., 2010). Although energy is an important resource for the economy, ensuring energy development for the Indonesian population has become a burden for the country. Substantial government funds are for fuel subsidies and in energy poverty reduction programs. Fuel subsidies affect the government budget significantly. In 2005 the Government of Indonesia spent over $13 billion dollars in fuel subsidy which represent of 20% government budget (Olivia and Gibson, 2008).

Fuel subsidies are mainly given to the residential sector which is one of the biggest sectors consuming energy. The practice of fuel subsidy can be traced back to the 1980s, when the government decided to control the country's internal oil price despite the fluctuation of world oil price. The decision to maintain fuel subsidies is mainly to ensure socio-political stability (Dartanto, 2013). Increased oil prices in the 2000s affected the growth of non-fossil energy such as biodiesel. The influence of technological factors were seen in the 1900s during the transition from coal to oil where the development of the internal combustion engine was the main driver for the substitution of coal with oil used as a fuel in shipping in 1950 and diesel locomotives in 1960 (Bee, 1984).

1.4.3. Energy access

Providing an energy access in Indonesia has a big challenge. Currently there are two main issues in the Indonesia energy access which are access to electricity and clean cooking. At national level the electrification ratio is around 80% however in some area the electrification only reached 60% with the poor quality that experiencing blackouts with lasting to 4 hours a day (ADB, 2016). Providing energy access by ensuring access to affordable, reliable and modern energy also align with UN SDG 7.1 – universal access to electricity and clean cooking. A transition from the use of traditional biomass to cleaner fuels and diffusion of clean and efficient cooking fuel would help to mitigate problem in energy access. While in the electricity, energy access can be achieved by extensions of electricity grid and decentralized microgrid (Riahi et al., 2012).

Energy access is an important aspect in energy system in Indonesia, where energy infrastructure development will affect the access of energy and delivery to the user (Marquardt, 2014). Indonesia, as of 2015, has an electrification ratio of around 80%, generating a capacity of around 85% with an annual growth rate of 8.4% since 1990; this capacity and rate of change will have difficulty in meeting future electricity demand (Rachmatullah et al., 2007).

The socio-political aspect of energy access has also become the focus of various studies. Energy development might solve a number of social problems such as reducing poverty and unemployment (Amir et al., 2008). The change to the use of modern energy sources such as LPG also contributed to reducing the energy poverty due to cheaper energy prices (Andadari et al., 2014). The energy system in Indonesia involves many stakeholders which form a complex interaction. For example, in the energy access improvement, the conflicting policies between ministries such as energy, environment, and industry or between central and regional government has occurred frequently during energy policy development (Agustina et al., 2012) (Austin et al., 2015)

1.4.4. Political economy

During the 1970s oil to gas transition, economic factors played a more significant role. During this period, the global demand of energy supplies in the 1970s such as gas in Japan and coal in China and India influenced Indonesia's energy transition. The majority of gas production at that time was exported to Japan in the form of LNG, and the majority of coal (i.e. 70% of all coal extracted in Indonesia) was exported to China and India. These global demands are still relevant today, as of 2014, India is the first destination for Indonesian coal accounting for 35% of coal exports, followed by China at 16% and Japan at 15%. Therefore, this situation drives energy policy in Indonesia to focussing on gas and coal energy which lead to bigger share of gas and coal in energy mix.

The liberalization of the electricity market in Indonesian during the 1980s gave the chance for private companies to be involved in electricity generation which led to geothermal energy development. Geothermal energy at that time was considered as economically feasible thanks to foreign investment and government incentives and subsidies (Hochstein and Sudarman, 2008) and also the benefits that a move to renewables would have on the environment (Nasruddin et al., 2016). Each of these transitions that have occurred are unique, for example environmental pressures were not considered during the rapid growth of coal production from 4.4 Mt to 80.8 Mt between 1989 and 1999 (MOEMR, 2017).

Energy sector is one of Indonesia government priorities especially in relation with climate change. Indonesia responding by developing various program to reduce national emission and comprehensive action to achieve this target. Indonesia's commitment follows a national target announced at the G20 summit in Pittsburgh in 2009, this commitment later elaborated in the National Action Plan for Greenhouse Gas Emission Reductions of 2011 by reducing emissions by 26% unilaterally, or by 41% with international support (Alisjahbana and Busch, 2017). Energy system in Indonesia are characterized by a large dependency on fossil fuels (Othman et al., 2009), the use of traditional biomass that contributes to air pollution and associated serious health risks (Ezzati and Kammen, 2002), and a rapid energy consumption which has lead to unsustainable energy development. For example, between period of 2003-2013, the average energy consumption growth is 5.5% annually while energy production such as oil lifting is declining at 2.2% and gas lifting is declining at 2% annually between 2010-2016 (Tempo, 2016). Gas energy reserves is also decline at 0.2% (DEN, 2014), therefore without new discovery of fossil fuel reserves the current energy development is unsustainable.Transition to renewable energy is inevitable due to scarcity of fossil fuel, with the current rate and without any new energy discovery the energy is only available until 2030 (Kompas, 2018). Therefore, there are a number of initiatives by Indonesian government for transition in clean and renewable energy. Transition to sustainable energy such as clean and renewable energy is required to not only to ensure the energy availability but also reduce the impact of energy development on human health and climate. An ineffective energy and environment policy is an important cause of such unsustainable development (Hasan et al., 2012).

To mitigate this problem an energy transition to a more sustainable energy supply is required; this transition should be assessed in term of physical, social, economic and political issues that will determine its feasibility and hence will be explored in relation to the energy transition literature placed in the context of Indonesia. The development of this sustainable energy transition scenario will use both quantitative and qualitative energy system modelling approaches and understanding.

1.5. Research questions

The overall goal of this study is to identify a feasible energy transition scenario for the country that could provide most benefit in terms of environmental sustainability in terms of GHG and air pollution emissions. To achieve this goal the following four research questions have been addressed in this thesis:

1) How does the current energy system in Indonesia impact on atmospheric emissions of air pollutants and GHGs?
2) What are feasible options for future energy transitions to more sustainable energy systems? How does the geography of Indonesia influence feasible energy supply?
3) What are the current and future impacts of atmospheric emissions from the energy sector on human health and global mean temperature?
4) Which energy transition scenario would optimize transition towards more sustainable energy system?

1.6. Thesis structure

The outline of this thesis will be described as follows:

Chapter 1 Introduction. This chapter explains the environmental problems associated with energy use and supply in Indonesia. It focusses on atmospheric pollutants and in particular air pollution and greenhouse gases. It provides an indication of the knowledge gaps in this area of research and how this thesis will conduct research to fill this knowledge gap.

Chapter 2 Energy transition. This chapter explores the existing literature of energy transitions that can be used to optimize future energy systems. The mitigation of the impact of energy production and consumption such as climate change and air pollution are required to ensure energy and environment sustainability.

Chapter 3 Emission inventory. This chapter describes the compilation and analysis of an air pollutant emission inventory (EI) for Indonesia for the year 2010. This comprehensive national air pollutant emission inventory is developed for Indonesia which, for the first time, covers all major sources of emissions. Although an emission inventory for Indonesia has recently been compiled by Permadi et al (2017), this did not cover several important sources such as CH_4 from rice paddy, livestock enteric fermentation, municipal solid waste in landfill and wastewater.

There have also been several regional studies that include emissions estimates for Indonesia (e.g. (Streets et al., 2003) (Zhang et al., 2009) (Kurokawa et al., 2013)) but these were mainly based on internationally available data and not developed specifically for Indonesia. This emission inventory will be used to understand how the current energy system contributes to emissions of atmospheric pollutants. There are 11 pollutant species covered which are SO_2, NOx, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC, OC, CO_2 and CH_4. The sectors that covered are energy industries, manufacturing industries and construction, transport, fugitive emission for fuels, transport, industrial process, solvent, agriculture, vegetation and forestry, waste.

Chapter 4 Emission scenario. This chapter describes the development of energy scenarios in Indonesia. Energy transition scenarios are developed for Indonesia, which are based on modifying existing Indonesian government energy transition scenarios through an assessment of their feasibility achieved by conducting interviews with stakeholders on energy and related sectors in Indonesia. In this chapter, a baseline scenario is developed to represent a business as usual approach. Three alternative scenarios also developed, each with different approaches to sustainable development of energy systems, one which focusses on clean energy, one on renewable energy and one additional energy transition scenario is developed to reflect a maximum feasible renewable energy based on geographical analysis on island's energy source availability.

Chapter 5 Impacts assessment. This chapter is an analysis of the environmental impact of the different energy scenarios within Indonesia. Here the focus is on environmental impacts resulting from atmospheric emissions that result in air pollution and radiative forcing. The chapter focusses on air pollution impacts to human health and for radiative forcing on the changes in climate temperature. The tools that used in this chapter is LEAP-IBC. LEAP-IBC is a tool that can be used to calculate human health and climate benefits resulting from altering atmospheric emissions.

The method is to determine the wider environmental impacts resulting from the energy development and to what extent renewable energy or clean energy sources can help to overcome these impacts. This chapter also describes the assessment of biodiesel energy development and the relation with forest fire in Indonesia. This analysis considers impact of biodiesel energy development from both direct emission from biodiesel consumption as well as indirect upstream emission from forest fire related biodiesel production.

Chapter 6 Conclusion. This chapter is about research conclusion, including summary of finding, recommendation for further research and policy implications.

Notes

Chapter 2 Energy transition relevant to Indonesia

2.1. Introduction

Energy production and consumption is the main contributor for the release of greenhouse gas and air pollution. The use of fossil energy has been identified as key contributing factor in energy system. Therefore, transition to clean and renewable energy is important for sustainable energy development. Currently, more than 4,000 articles have been published in the area of energy transition since early 1900s considering many of the challenges associated with energy supply and demand including the economics, accessibility, technological invention and environmental sustainability of our energy systems (Araújo, 2014). Therefore, its hard to find a theory that encompasses all factors that might be important for particular situation such as time and place.

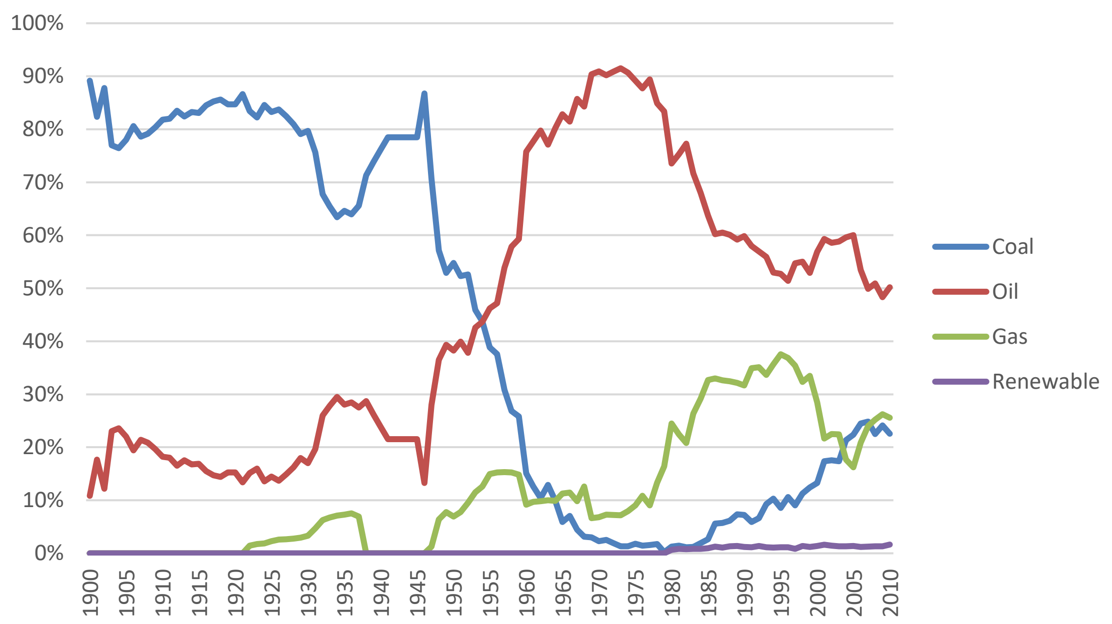

Figure 2-1 Historical energy mix transition in Indonesia

Energy systems can be defined as all components related to the production, conversion, delivery, and use of energy (IPCC, 2013). Indonesia's energy system is complex and over the last century its energy mix has been constantly changing. Until the 1940s, coal dominated and accounted for more than 90% of Indonesia's energy mix. In the 1970s, oil dominated comprising more than 70% of the energy mix and in more recent decades, renewable energies such as geothermal energy and biodiesel have begun to increase their share of Indonesia's energy mix as shown in Figure 2-1 above.

Energy transition studies have a difference from other studies in the way they see the process of change, structure of change and timing of changes; this is the main factor which defines the various energy transition theories. The purpose of energy transition studies in this thesis is to see which of these energy transition approaches is most relevant for Indonesia and for a transition to sustainable development by analysing the literature that relevant to energy transition in Indonesia. The understanding of the aspects of energy transition will be used to develop a number of feasible energy scenarios that can be explored using scenarios and planning tools. Various energy transition studies that might be applicable for Indonesia will be described in this chapter.

Sustainable energy in this thesis refer to common definition according UN to is an energy system that serves the needs of the present without compromising the ability of future generations to meet their needs especially in term of environmental impact.

Further, as archipelago country consisting of more than 17,000 islands, with varying degrees of population density and economic activity it is important for Indonesia to consider the geographical challenge in the energy transition (Hasan et al., 2012). The geographical challenge, which refers to the large variability in energy supply, between the islands in Indonesia is one of the biggest challenges to designing energy and environmental policy in Indonesia that is often neglected (Bee, 1984). Geography plays important roles in Indonesia’s energy supply as each island has different energy sources and different energy distribution system. Therefore, it is important to have a energy policy and analysis that consider the geographical aspect of energy in Indonesia.

2.2. Energy modelling

Modelling approaches or scientific modelling, are a quantitative approaches that aim to understand, define, quantify or simulate a complex and interrelated system such as the environment or economic system by referencing it to existing and usually commonly accepted knowledge (Bousquet et al., 1999) (Beven, 2010). A modeling approach is very useful to explain the complex interrelationship in the energy system such as how it is related with supply and demand of different sectors and output (emissions, economics, trade). The modelling approach provides a powerful means of exploring the dynamics of the system and it plays a crucial role in thinking about how every aspect in the system might develop in the future.

2.2.1. Energy system modelling

In the context of the energy system, the modelling approach is powerful to explore the dynamics of energy system and how each aspect in the energy system such as energy supply and environment is related. The modelling approach is built for various complex systems with different purposes (e.g. environment or energy models). Within these models are several embedded models each built with their own purpose such as to simulate or optimize energy supply and demand. Modelling approach also used to have a conceptual interaction of various sectors and output related with emissions, economic or trade.

For example, in the energy model, currently, there are several energy modelling tools used for analyzing energy systems which were designed for a number of purposes, such as for better optimization of the design of the energy supply system given a level of demand forecasts, better simulation to understand of the present and future demand-supply interactions, and better energy and environment interactions, energy-economy interactions and energy system planning (Bhattacharyya and Timilsina, 2010).

Modelling approaches can either be classified as top-down or bottom-up. Top-down modelling is based on macroeconomic modelling principles and is intended to include important economic interactions within society. Top-down modelling is characterized by behavioral relations at an aggregated level with parameters estimated based on historical relationships. Bottom-up modelling is based on disaggregation and technical parameters. Bottom-up modelling requires the energy system to be described in detail and includes information on a number of specific energy technologies with both technical and economic parameters. A hybrid modelling approach is combining both bottom-up and top down approach (Klinge Jacobsen, 1998).

Each energy model is built for specific purpose depending on its geographical coverage and its timescale. Geographical coverage means in what area is the energy modelling to be analyzed. Energy model can focus on a global level covering the world, the regional level covering several countries or even developed to cover local level such as city or islands. The energy model can also be analyzed over a certain time scale such as on hourly, daily or annually. A comparison of energy models given in Table 2-1.

Table 2-1 Comparison of energy modeling (Urban et al., 2007)

Approach	**Methodology**	**Geographical Coverage**	**Timescale**	**Examples**
Bottom-up	Accounting	National, regional	Annual	LEAP
Bottom-up	Simulation	National, regional, local	Daily, Hourly	EnergyPlan, PowerPlan
Bottom-up	Optimization	National, regional	Daily, Hourly	MARKAL
Bottom-up top-down (hybrid)	Equilibrium	World (global), regional	Annual	WEM

The bottom-up type of energy model is a popular and widely used in energy modelling. The bottom-up models can be based on accounting of energy supply and demand or can be based on simulation of energy production and consumption such as EnergyPlan and PowerPlan. Bottom-up models work by analyzing the energy balance, i.e. energy supply and demand, in the energy system. Bottom-up models use the supply of energy and sectoral demands from transportation, industry, commercial and residential sectors, including export and import, to define the composition of energy use and supply for a defined energy system. Bottom-up energy model are widely used and often form integral parts of energy policy evaluation by government or others research institution and non-government organization.

The LEAP (Long-range Energy Alternatives Planning) energy model developed by the Stockholm Environment Institute (Heaps, 2008) is a type of accounting bottom-up energy model. LEAP is widely used by countries all over the world (Suganthi and Samuel, 2012). For example in Indonesia, the LEAP framework is used by the Ministry of Energy, Ministry of Environment and the Ministry of Research and Technology (MOEMR, 2017). In Indonesia, the LEAP framework has been used for developing national and regional energy planning, greenhouse gas analysis and supply and demand analysis. For example, LEAP is used by Ministry of Energy in 2014 to estimate the growth of energy consumption in 2025 and 2050. LEAP estimated the energy consumption will be reach 400 Mtoe (million tonnes of oil equivalent) in 2025 and 1200 Mtoe in 2050 (MOEMR, 2017). This analysis is used further to develop energy and environment policy in Indonesia.

The EnergyPlan energy model is a simulation type of bottom-up energy model developed by Aalborg University, Denmark (AAU, 2017). EnergyPlan is energy model that focusses on renewable energy integration. Energy plan analyzes the optimal design of the energy system, including technical workings and feasibility of a given energy system or a given energy scenario (Østergaard, 2015).

The PowerPlan energy model is also a simulation type bottom-up energy model developed by Groningen University, Groningen (RUG, 2017). PowerPlan is an energy model that focusses on simulation of electricity generation. PowerPlan can be used to analyze the transition towards a sustainable electricity production (Thiam et al., 2012).

Energy models have been developed to address specific technological and policy instrument challenges. LEAPs strength for example is on the coverage of various energy production technologies from traditional wood biomass to renewable energy. LEAP has bigger coverage of various energy production technologies from wood biomass to renewable energy across all sectors and energy supply. To accommodate this challenge, LEAP is designed based on accounting model to ensure that all energy system and sectors covered. By contrast, tools such as EnergyPlan and PowerPlan emphasize certain aspects of energy systems such as renewable energy in EnergyPlan and electricity generation in PowerPlan. Both EnergyPlan and PowerPlan main strengths are their simulation methodologies where completeness of every sectors data is not prioritized.

MARKAL is an energy model that focusses on optimization of energy systems such as energy costs, plant costs, plant performances, building performance that developed to represent the evolution (over a period of usually 20–50 or 100 years) of a specific energy–environment system at the global, multi-regional or national level. The MARKAL energy model has been developed in a collaborative effort under the auspices of the International Energy Agency (IEA). Unlike the bottom-up simulation and accounting models, MARKALs strength is on the optimization of energy system. MARKAL is also widely used in developing countries to find economically optimal energy systems for clean energy transition (Das and Ahlgren, 2010) or for low carbon development (Shrestha and Shakya, 2012).

The World Energy Model (WEM) is an energy modeling approach that is used by the International Energy Agency (IEA) for World Energy Outlook (WEO) publication. WEM has been used by IEA since 1993. WEM focuses on economic aspects such as the investment payback periods or cost optimization of energy systems (Kesicki and Yanagisawa, 2015).

Unlike other energy models that work on regional or country levels, WEM works on the global level covering all countries in the world. WEM also works using both top-down and bottom-up modelling which tries to find the equilibrium in the energy, environment and economy. The WEM model is based on three main components: final energy consumption, covering residential, services, agriculture, industry, transport and non-energy use; energy transformation, covering power generation and heat, refinery and other transformation; and energy supply, covering coal, oil, natural gas and biomass. The WEM approach relies on basic assumptions such as GDP and fuel prices and needs extra attention to avoid bias in the calculation (Liao et al., 2016).

Impact assessment

LEAP-IBC (Integrated Benefits Calculator) is an application of LEAP that allow quantification of air pollutant and greenhouse gases impact on human health, crop loss reduction and climate. As ambient air pollution health impact assessment tools LEAP-IBC requires information about air pollution concentration, the relationship between concentrations and health outcomes and the characteristics of the populations exposed, including their baseline health status, age, and location (Anenberg et al., 2016). A comparison of health impact assessment given in Table 2-2.

Table 2-2 Comparison of impact assessment tools (Anenberg et al. 2016)

Approach	**Geographical Coverage**	**Pollutant**	**Health Outcome**	**Examples**
Emissions	National	$PM_{2.5}$, O_3, NO_2, SO_2	Mortality	LEAP-IBC
Emission	City	$PM_{2.5}$	Mortality	AirCounts™
Concentration	National, Regional, City	$PM_{2.5}$, O_3, NO_2, SO_2	Mortality, Disability, Morbidity	BenMAP-CE
Economic and climate indicator	National, City	PM_{10}	Mortality, Disability	GMAPS

Each impact assessment tools have their specific purpose such as pollutant, geographical coverage and impact outcome. The main difference between each assessment tools is on the user input that used in the application. LEAP-IBC is used in the thesis as the input data is from the emissions data.

2.2.2. Quantitative and qualitative modelling

The energy theories described above represent a system of assumptions, principles, and relationships to interpret and explain a social phenomenon, in this case energy transitions (Seidman, 2016). An approach is whole set of methods developed to achieve something (Gerring, 2001). A theory is used to explain why energy transition happened in the past and how energy transition will be performed in future, while the purpose of a methodology is to implement something for example environmental policy targeted towards a particular energy transition.

Generally, there are two main analytical approaches that allow us to analyze energy transitions : quantitative models and qualitative information or narratives (Söderholm et al., 2011) (Swart et al., 2004). The quantitative approach of energy transition uses mathematical techniques such as statistical or network analysis to project and analyze consequences and impact of certain energy policies in the future. A quantitative approach using energy modelling tools is designed to help with the analysis of some situations and estimate the impact (e.g. on the environment, social factors and the economy etc.) of future energy supply and use scenarios. Unlike the qualitative approach that focuses on the narrative of energy and explores external factors that affect the energy transition; the focus of the quantitative approach is a projection of the future energy production, consumption and its impact in the energy system.

The qualitative approach uses sociological framing and narratives such as energy transition theory (Turnheim et al., 2015). A major reason for adopting a qualitative approach as an analytical tool for considering possible energy transition pathways is to represent the dynamics of social change in the energy system (McDowall, 2014). The purpose of qualitative energy transition is to provide a descriptive study where the attention is focused on actors, behaviors and institutions.

The qualitative approach cannot inform the feasibility of the scenario developed using the quantitative modelling approach, however it can provide additional alternative scenarios that are based on the broader socio-political context (Söderholm et al., 2011). The alternative scenario is based on other assumption that is not included. The qualitative approach uses techniques such as interviews or focus group discussions to explore the possible pathways of energy policy development. Qualitative approaches are based on explorative modes of future thinking and creative thinking (Söderholm et al., 2011). Qualitative techniques are able to capture influencing factors in energy transition such as values, culture and institutional features (Swart et al., 2004).

The relationship between quantitative and qualitative approaches is described in Figure 2-2 (Spyridaki and Flamos, 2014). It describes the two-common approaches that can be used to achieve energy transition and the various options that can be used for evaluation or development of policy. For example, in the quantitative approach bottom up or top down energy modelling can be used to assess the impact of energy transition on the society, energy and environment. In the qualitative approach, there are several options that can be used such as social analyses or evaluations of policy. Both of these approaches are widely used (Mahony, 2014), (McDowall, 2014) to explore the probable future of energy transition using integrated approaches (Robertson et al., 2017).

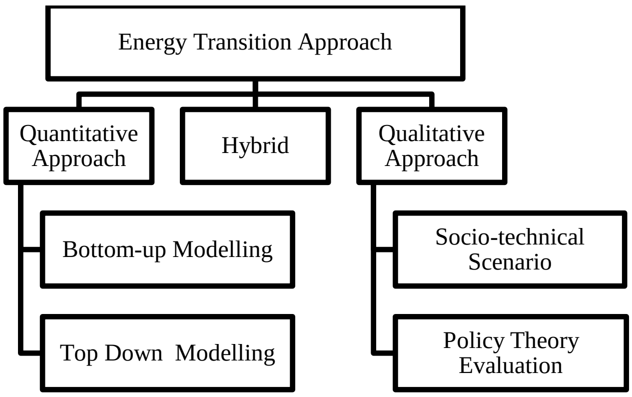

Figure 2-2 Energy transition approach (Spyridaki and Flamos 2014)

In the quantitative modelling approach, energy transition can be described as a projected scenario that tries to answer the question "what will happen". This perspective would help to understand emission reductions or the level of energy supply required to meet demand which can be measured in quantitative terms (Söderholm et al., 2011). By contrast, the qualitative approach describes energy transition as more of an explorative issue and tries to answer the question "what can happen" and "how can a specific target be reached". For example, the level of energy production will double in 20 years or the level of emissions will be reduced by 24%.

Another approach that can be used is the integrated approach. The integrated approach combines both quantitative and qualitative approaches. The integrated approach is widely used since it involves a more comprehensive assessment of the energy system (Spyridaki and Flamos, 2014). The integrated approach is achieved based on iterative interactions between stakeholders (Turnheim et al 2015). This iteration can produce a more comprehensive and useful chain of assessments to support policy formation and action (Geels et al 2016).

Energy models are developed to address specific challenges, there is no single energy model that is appropriate for every situation. Most of the recently developed energy models can also be used to develop future energy and associated pollutant emission projections which means energy models now have a similar functionality.

The strength of energy models is in their use to understand the pros and cons of different energy systems. One of the ways to assess which energy model is most appropriate for different uses is to consider the key strengths of each model. LEAP for example is a powerful scenario analysis tool that can be used to describe, compare and analyze individual policy measures. LEAP can also be the focus of simulation of the energy system and capacity expansion planning. LEAP is also very strong in impact and environmental analysis of energy systems. Moreover, LEAP is one of energy models that has a high number of users around the World with more than 5,000 users. LEAP is also free for developing countries which is why LEAP is widely used and has a bigger user base. However, LEAP also has a weakness especially in its capability to analyze price induced policies.

MARKAL is the strongest energy model that focusses on optimization emission and economic by selecting the set of energy system options. Unlike other energy model, MARKAL has capability to perform optimization in the daily and hourly timestep. However, a major weakness of MARKAL is the lack of information related to the environmental analysis of energy systems. Moreover, MARKAL is a commercial software and the user base is limited to around 100-1000 user across the World, therefore it is not as popular as LEAP.

WEM works on global level which makes WEM very different with other energy models. WEM also supports price induced policies which are not strongly covered in other energy sector models. WEM focusses on energy poverty and various energy economic policy challenges. However, WEMs weakness is on its capability to assess renewable energy integration or energy optimization. The focus of this thesis is to understand the wider environmental impact of energy systems through scenario analysis. This key challenge is only addressed by the LEAP model.

2.3. Energy transitions theory

The popular definition of energy transition is a long term change in the energy system (Smil, 2010). However, the exact definition of energy transition varies from one study to another. Energy transition is described as changes in the energy system, such as changes in the composition of energy supply (energy mix), changes in the energy balance between supply and demand, or changes in energy usage patterns (Sovacool, 2016). Energy transitions can be described as economic transformations to reduce emissions or development in energy technology (Araújo, 2014).

Energy transition can also be brought about by major technological transformations in the way society functions (Geels, 2002). Geels (2002) see energy transition as a social process, where an energy transition will depend on the government, industries, and customers as a complex system. Other studies see energy transition as a geographical process, where an energy transition is partially shaped and influenced by geographical elements such as the location of energy resources and distances to different groups of energy consumers (Calvert, 2015).

As the purpose of energy transition studies is to explain these complex systems and how they can change, it is important to understand the key differences in the concepts behind energy studies. Most energy transition studies have a fundamental difference in the way they see the process of change, the structure of change and timing of changes; this is the main factor which defines the various energy transition theories.

Energy transition tries to describe a complex system, through an understanding of structures and processes that exist in different societal domains, that occur on a range of scales and involve various actors with dissimilar perspectives, norms, and values (Loorbach, 2010). Energy transition happens in parallel with other technology transitions, and it involves several aspects of change in various areas such as technology, organization, institution, socio-political and cultural aspects (Markard, 2012). To avoid making oversimplifying assumptions, a careful process definition should be established to avoid important factors and social considerations being neglected in the analysis of energy transitions (Miller et al., 2015).

Energy transition tries to describe a complex system, through an understanding of structures and processes that exist in different societal domains, that occur on a range of scales and involve various actors with dissimilar perspectives, norms, and values (Loorbach, 2010). Energy transition happens in parallel with other technology transitions, and it involves several aspects of change in various areas such as technology, organization, institution, socio-political and cultural aspects (Markard, 2012). Therefore, understanding energy transition will be very important to ensure the energy system transformation is developed and reach the target while minimize the environmental impact.

Finding an appropriate energy transition theory that can most usefully understand energy transition in developing countries such as Indonesia will depend on how these theories deal with the key factors that determine the feasibility and effectiveness of transitions to a particular energy mix for a particular end goal. Therefore, for Indonesia context, energy transition is related with development of the national energy policy.

Based on the literature described, there are several energy transition theories and body of literature that might help to understand the complexity of energy transition in Indonesia. Theories such as 'Multi-level Perspective' (Geels, 2002), 'Technological Innovation System'

(Bergek et al., 2008) and body of literature such as and 'Energy Geographies' (Calvert, 2015) may all help to allow a better understanding of energy transition in Indonesia. In this chapter how these theories have applied in examples of Indonesian contexts will be explained.

Multi-level perspective (MLP) (Geels, 2002) believes that energy transition happens in different layers from the lowest level of technological niches to the highest level of landscape development (such as government policy). The analytical framework of MLP can help to describe the process of energy transition and how change takes place. The key components of MLP theory are the structural and process components. The structural component has an emphasis on who participates in the energy transition, while the process component emphasizes how the transition happens. These dynamics of MLP are described in Figure 2-3.

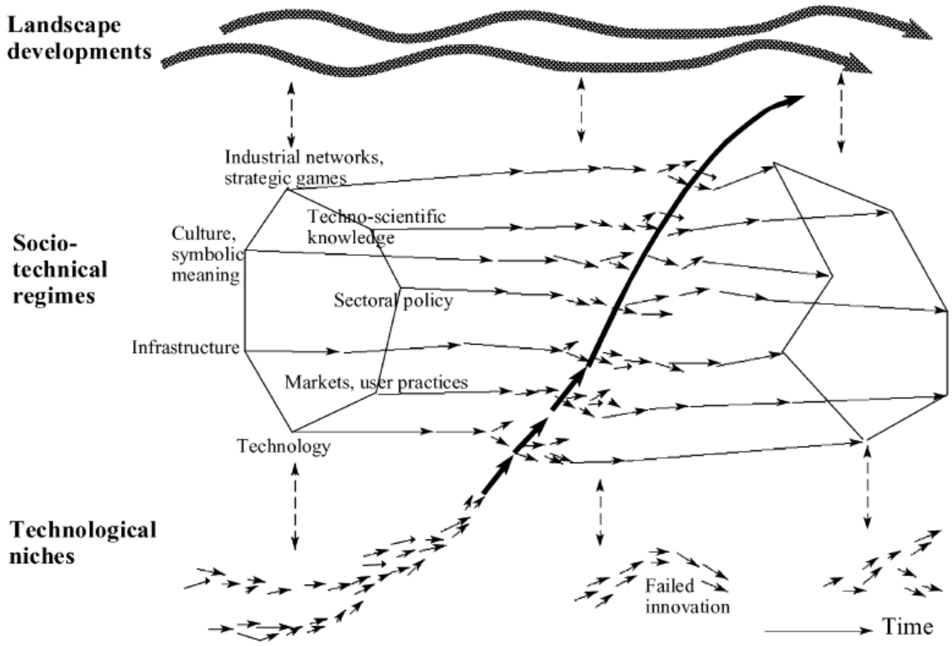

Figure 2-3 Dynamic multi-level perspective (MLP) theory (Geels, 2002)

It is also important to understand that each of energy transition theory that selected has specific emphasis on the drivers of energy transition. For example, MLP, places an emphasis on multi-layer transitions, TIS on innovation and energy geographies on geographical features that drive transitions. As a conceptual framework, both the MLP and TIS theories are very similar. MLP and TIS uses a social analysis paradigm, exploring both structure and process of social systems. These theories assume that certain themes are affecting the transition with MLP assuming that governance is a key driver of the transition, while TIS considers innovation as the main driver.

The MLP theory explains the transition through a sequence of social processes from niche development to breakthrough and substitution, by contrast, TIS explains the transition as a similar sequence of social processes from entrepreneurial processes to market formation. As explanatory tools, both MLP and TIS theories are also able to capture the uncertainty in the early phases of technological development, either as niche development or as innovation development, both in formative phases (Rip and Kemp, 1998). The key concept, functional dynamics and interaction of TIS theory is shown in Figure 2-4.

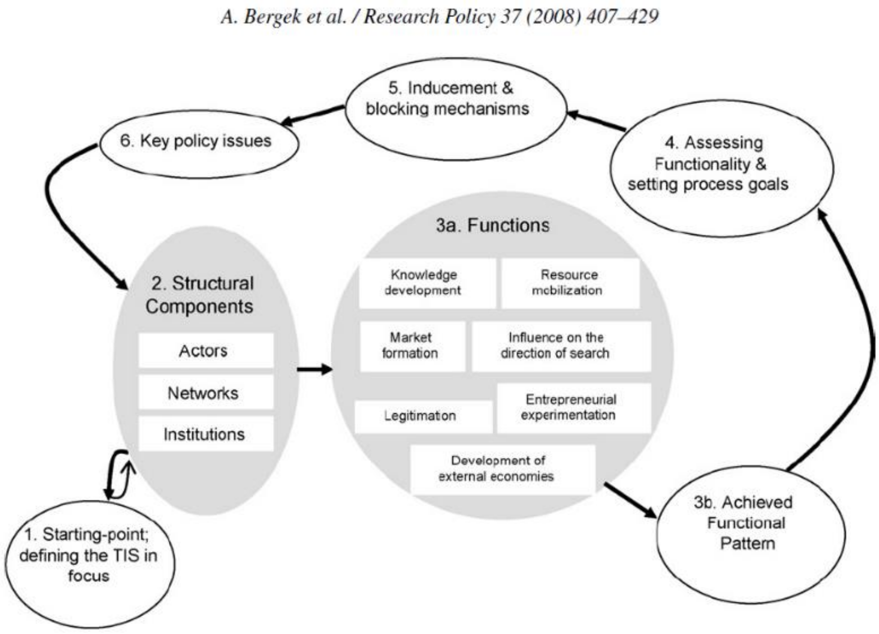

Figure 2-4 Dynamics of technological innovation systems (TIS) theory (Bergek et al 2008)

These theories also can explain how gradual changes occur leading to overall energy transitions. The difference in nature of the practicalities of these theories means that the timeline of the pathway to energy transition will differ which is an area also important in terms of research to understand these theories and energy transition in practice. For example, TIS theory is more interested in development of specific energy resources such as solar and PV, whilst MLP is more interested in the development of general energy transition. The energy geography theory is particularly useful to understand energy transition in Indonesia given its geo-spatial diversity in issues related to energy supply, use and demand.

The MLP, TIS and energy geographies theory provide useful conceptual frameworks to help explain and understand energy transitions that have, and have not, been successful in the past. Although in these fundamental principles, MLP and TIS theories are very similar, at the practical level, they have rather different paths of energy development. Most of case studies on TIS theory are specific and concerned with successful diffusion of a particular technology. This explains why the TIS theory is very popular for use in understanding specific approaches to energy generation technologies such as solar PV and biodiesel. Meanwhile, the MLP theory usually has a general approach focusing on prospects and the dynamics of the broader transition processes or varieties of innovation.

The location of energy resources is very sensitive to geographical position. Energy production is site-specific, and has physical constraints such as climate, land-cover, and terrain that cannot be modified. These therefore set absolute limits on the scale and intensity of energy production that can be achieved (Calvert, 2015). Energy geographies is an analytical framework that is based on the principle that energy transition is a geographical process that is affected by geographical features such as location, landscape, territoriality, spatial differentiation and scaling. According to Bridge (2013), location is defined by the physical places where energy sources are located. Territoriality is defined by how the energy production network is organised geographically to generate and capture value. Scaling is how material and area size affects development of energy, where different size of energy development affects the price and economics of energy.

Various studies have indicated the importance of geography in energy transitions (Bridge et al., 2013) and how the geography of low carbon transition (Bulkeley et al., 2014) might help to understand the complexity of energy transition. Having a geographical perspective on energy might provide an advantage in understanding global energy trade networks, energy planning, energy access, security, technology implementation and a host of other concerns (Calvert, 2015). The emphasis in energy geography theory is analysis of spatial dimensions in a more systematic way (Huber 2015).

Energy geographies might be very useful in analysing dynamics that involve complex geographical features and large variations between areas. This emphasis and investigation on spatial dimensions in a more systematic way might provide a better method for determining energy transitions in Indonesia (Huber, 2015). For example, in Indonesia, geothermal energy only available in certain islands such as Jawa and Sumatra. Kalimantan island which the second largest islands has no geothermal energy. Another example, in Indonesia, not every place has an equal energy source. The average wind speed in Indonesia is about 4-5 m/s, the higher wind speeds of about 6 m/s are located in the eastern part of Indonesia.

Proximity factors, such as how far the energy source is to the customer are also important. For example, the distance of the coal mine to the nearest electricity power plant will affect the energy transition of certain locations. In Indonesia, although coal is abundant, majority of coal is exported therefore some area with rich coal might have lowest energy access. Therefore in recent Indonesia energy policy, a coal mine mouth (CMM) power plants is prioritized in the energy policy due proximity of coal mining with the power plant (Cornot-Gandolphe, 2017).

Geographies of renewable energy generation can be seen from the recent influx of foreign investment into Indonesia's solar PV sector. Given Indonesia's archipelagic geography, off-grid renewable technologies such as solar PV that produce electricity with a very low climate impact could be an effective means of addressing the low electrification challenge, while also reducing reliance on expensive emissions-intensive diesel generation. However, high perceptions of risk and limited opportunities for developers to exploit economies of scale from distributed energy projects have produced a geography of renewable that characterized by large-scale projects in location that typically already enjoy reliable access to electricity (Kennedy, 2018).

The focus of this thesis is to understand the environmental impacts associated with energy supply and use in Indonesia and to identify an energy mix for the country that would be more environmentally sustainable; understanding the feasibility of transiting towards this energy mix is important to be able assess the likelihood of occurrence of different energy scenarios. Since the MLP theory is able to understand the impact of energy transition including successful transformative societal processes, it is felt that this theory is more suitable to explain the energy transition in Indonesia. MLP emphasis on the governance of energy transition might help Indonesia in designing effective energy transition policy. There MLP would be the most useful for Indonesia to help drive forward as successful energy transition. However, to have a more comprehensive energy transition, geographical aspects of energy transition also should be used especially in relation of the islands variability of energy mix that will affect the energy policy.

MLP in this study will be used as guiding principles in policies development where the aim of energy transition is through societal transformation. By using MLP theory, it can be argued that policies development should be implemented with emphasis to governance aspect to ensure that every stakeholder is involved in the energy transition. In the policies implementation level, the energy policy will be implemented by following MLP principles such as on the understanding key stages of energy transition. Finally, this guiding principle will be translated into scenario development where it involved the stakeholder input in the policy making and how the society responding on the policy. According to MLP, a policy should be able to balance every stakeholder interest and cover input from every stakeholder.

Choosing MLP also has a weakness in contrast with TIS; MLP can be argued to be too broad and unable to capture the prospects and dynamics of specific innovations. In Indonesian context, MLP would have difficulty to explain why geothermal transition is successful in contrast with failure of solar PV or wind energy when the emphasis is innovation. In most of cases, MLP might be able to explain energy transitions in the household sector, such as why LPG transition was successful and the move to using coal briquettes was not. MLP is also be able to explain energy transition in the biodiesel sector, such as why palm oil was more successful than *Jathropa curcass*. However, MLP is unable to capture more complex energy transition that involved various technology innovations and complex infrastructures like electricity. To apply MLP as a conceptual framework will require the subjective, qualitative approach of MLP to be combined with a more quantitative methodological approach such as energy supply and demand modeling. In the policy implementation context, MLP should be combined with other quantitative approach.

2.4. Indonesia energy system

The Indonesian energy system reliant on a large use of traditional biomass such as fuel wood for cooking which dominates the residential sectors energy supply and use. For example, in 2011 it was estimated that 103 million people relied on wood fuel for cooking out of the 245 million total population (IEA, 2015). In 2015 it was estimated that 25 million of people who currently lack access to electricity (Kennedy, 2018).

Total Primary Energy Supply (TPES) is the total amount of primary energy that a country has at their disposal. According to IEA, TPES is defined as energy production plus energy imports, minus energy exports, minus international bunkers, then plus or minus stock changes which including any type of fuel, electricity in the country. The current day TPES energy mix for Indonesia (based on data for 2012) is dominated by oil (46%), followed by coal at 23%, gas at 24% and renewable energy, which includes geothermal, hydro, biomass and solar power at less than 5%. The large dependency on fossil fuels is a continuing characteristic of Indonesia’s energy supply having been present over the past few decades between 1980 to 2000s (Othman et al., 2009).

The energy mix or variability in the mix is a crucial factor determining the sustainability of an energy system. In Indonesia, this energy mix concept is used by the government to provide a target for energy policy. For example, based on the National Energy Policy of 2006, Indonesia is expecting to have increased its share of renewable energy from 5% to 25% by 2030. Despite the large potential for renewable energy use, the utilization of renewable energy in Indonesia is currently very low. For example, Indonesia accounts for 40 % of the world’s geothermal reserve (Rozali et al., 1993), but the geothermal utilization in Indonesia is less than 3% (Kumar, 2016).

Energy sector is one of Indonesia government priorities especially in relation with climate change. Indonesia responding by developing various program to reduce national emission and comprehensive action to achieve this target. Indonesia's commitment follows a national target announced at the G20 summit in Pittsburgh in 2009, this commitment later elaborated in the National Action Plan for Greenhouse Gas Emission Reductions of 2011 by reducing emissions by 26% unilaterally, or by 41% with international support (Alisjahbana and Busch, 2017)

Based on Nationally Determined Contributions 2016, Indonesia aiming for 29% of emission reduction funded by national budget, and 41% reduction with international support in 2030. Study indicated that for Indonesia, INDC presents two opportunities for developing countries: as an instrument in achieving the ultimate objective to reduce emission, and as a means for developing countries to integrate a climate compatible development to achieve low carbon and resilient development. Indonesia can make the most of NDC to achieve both development and climate goals in parallel (Imelda and Tumiwa, 2015) (Nakano et al., 2017).

Since the energy system is constantly changing and since this change can be to a certain extent controlled, it is important to study energy system transitions so that they can be understood and developed to be more sustainable. This is important to ensure the future of Indonesian energy supply and use both from the viewpoint of energy security, energy access, economics, politics as well as the sustainability of environmental aspects and the energy system. Energy transition studies help to understand the drivers and impacts of changes in the energy system so that effort can be directed into policies, technologies and socio-economic considerations to try to optimize future energy systems. Energy transition studies will be used to guide in developing energy transition scenario, analysis future impact and improve the quality of policies being made. This will be explained in the next section.

2.5. Energy transition in Indonesia

The following sections describe energy transitions which have been pushed forwards in Indonesia; not all of these have been successful and the factors that might have determined the success or otherwise are considered. These transitions are also considered to assess their ability to explain the relative success of the transitions. This type of critique is useful to assess the potential for future energy transitions that might be attempted in Indonesia.

2.5.1. Biodiesel transition

Biodiesel energy has been used in Indonesia since the early 2000s where the consumption is less than 1,000 kl. However, the rapid transition to biodiesel really began only between 2009-2014 where biodiesel consumption increased from 190,000 kl in 2009 to reach 3,319,000 kl in 2014 (MOEMR, 2016) as shown in Figure 2-5. The beginning of the biodiesel energy transition can be traced to a c, various sources of biodiesel such as *Jatropha curcass* and palm oil were used as biodiesel feedstock. Palm oil became the more favoured source of biodiesel rather than *Jatropha curcass* largely due to land use issues which saw the crop usually being grown by small farmers on unproductive land rather than on large scale plantation systems (Amir et al., 2008). This prevented the crop being grown at the scale required for use as an energy source. Biodiesel transition is successful in term of the amount of energy that consumed and can be used as a case study for energy transition in term to explain the roles of energy policy.

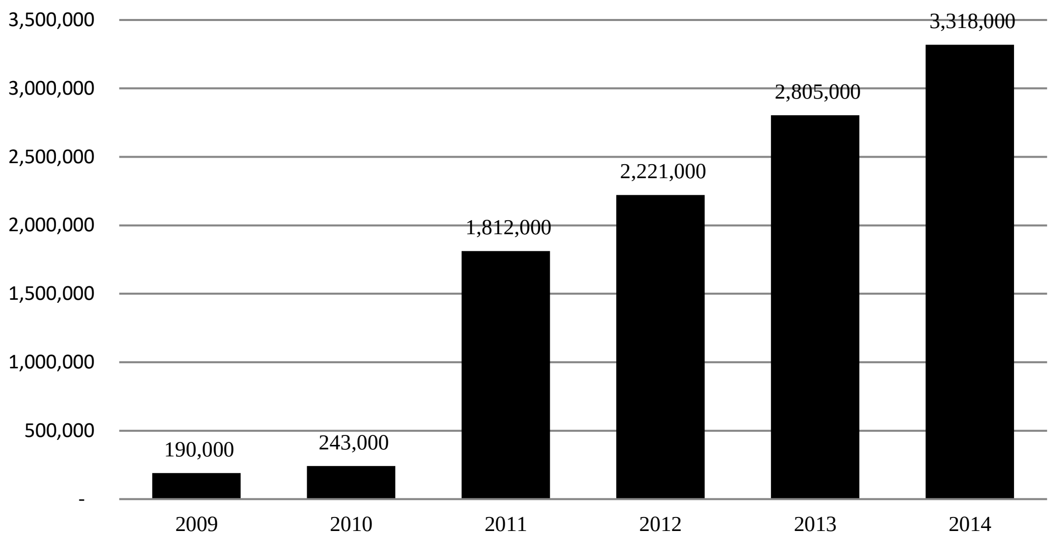

Figure 2-5 Biodiesel consumption 2009-2014 in kl

In Indonesia, biodiesel transition can be explained from MLP perspective. According to MLP, biodiesel transition in Indonesia follows process patterns from niche developments to learning, break-through and substitution. The niche developments of Indonesian biodiesel began in the early 1990s when a university and research institute manufactured biodiesel from various plantation products. Serious attempts to manufacture biodiesel on a large scale began in the early 2000s along with the niche development of various biodiesel companies. Various studies and research performed during this period lead to the successful and efficient production of biodiesel from various plantation products (Silitonga et al., 2011).

The breakthrough phase in the biodiesel transition occurred when a series of policies including mandatory biodiesel usage and Crude Palm Oil (CPO) Support Fund were established in 2010 to support the biodiesel transition. The support fund was used for the development and promotion of biodiesel energy. The biodiesel transition was successful leading to the mandatory usage of biodiesel of 10% mix (B10) in 2014 and increasing to 15% (B15) in 2015 indicating the beginning of the substitution phase. However, this transition is not without its problems, critics have highlighted how that the rapid increase of land use for palm oil plantations from 2.2 million ha in 2000 to 11.3 million ha in 2015 has been responsible for various environmental problems (Wicke et al., 2011).

2.5.2. LPG transition

Liquefied petroleum gas (LPG) has been used in Indonesia since the early 1990s as a household fuel but largely only by upper level income groups. At that time, the majority of Indonesian households were using kerosene and biomass as household fuels. The LPG transition began as a government initiative promoting LPG as an alternative fuel to replace kerosene that had previously been heavily subsidized; this was an important change since the price of kerosene, and hence the level of subsidy that need to be provided by the government, was increasingly being driven by the increase in the price of oil from which kerosene fuel is distilled. LPG was preferable as the price of production was relatively cheaper than price of kerosene (Budya and Yasir Arofat, 2011).

The LPG transition has been one of the most successful transitions and has led to the conversion of 50 million households that were using kerosene to change to using LPG fuelled stoves, this occurred in the period between 2007-2010 (MOEMR, 2014). Previously before 2007 LPG consumption is less than 20 thousand ton but later reach 3.9 million ton in 2012 as shown in Figure 2-6.

The LPG transition can be considered a successful transition towards a more sustainable energy system as measured by several indicators; these include reducing governments subsidy budget from 9-18% to 1.9-3.7% of total state expenditure (Budya and Yasir Arofat, 2011). Energy in Indonesia is heavily subsidized, this subsidy was one of the biggest in terms of government expenditure and was affected by oil price and foreign exchange fluctuation. From an air pollution point of view, LPG has also seen a decline in atmospheric emissions; within a 3 year period (2007-2010) the LPG transition has successfully replaced 4.9 Tg kerosene with 2.6 Tg LPG with reduction of 48 Mg SO_2 and 7.6 Tg CO_2 (Permadi et al., 2017).

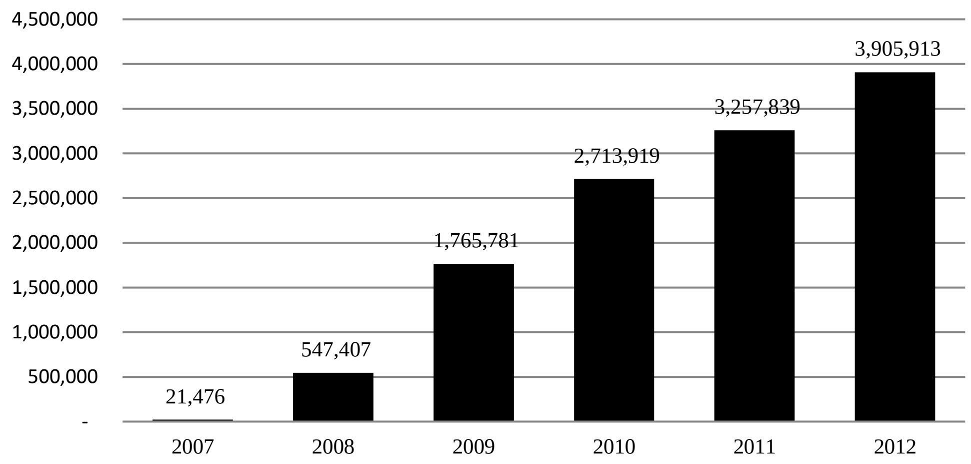

Figure 2-6 LPG consumption 2007-2012 in ton

LPG transition in Indonesia also can be explained from MLP perspective. LPG transition has seen the change of the main household fuel from kerosene to LPG. In Indonesia, kerosene was heavily subsidized, the production of kerosene was managed by the state-owned company, Pertamina. In the LPG transition, the landscape that affected the transition was increased oil price. As oil price increased, the price of kerosene also increased. The government of Indonesia therefore needed an alternative and cheaper fuel. The regime layer in the transition is energy production and distribution. The niche layer, where innovation happened, occurred with the use of different fuel types in households, these were manufactured by coal briquette production and LPG production companies.

During the LPG transition, niche development began in parallel with both LPG and coal briquettes being offered as alternative fuels for the household sector. The development of these alternative fuels was established in early 1980. At that time, PT Bukit Asam, a state own company involved in coal mining was developing a commercial coal briquette as an alternative to be used as a small, medium enterprise cooking fuel. Although commercially successful, the growth of coal briquettes use was very slow and the market size very small. At the same time LPG was also being marketed as an alternative household fuel but was less popular than coal briquettes.

The development phase of household fuels began in the early 2000s, at the same time as increases in oil prices were being experienced. Various studies explored which of coal briquettes and LPG would make the best alternative household fuel. The breakthrough phase in the household fuel transition occurred when the government of Indonesia began major conversion of household fuel from kerosene to coal briquette. At the same time, the conversion from kerosene to LPG was also ongoing. However, the transition to coal briquette was not successful, and the government decided that LPG should be the main fuel for household sector.

The failure of coal briquette in the household energy transition from MLP perspective can be attributed to several factors. First, from the distribution point of view, both of LPG and kerosene producer and distributor is under same company, which is Pertamina; this meant that a distribution network that could be used for LPG already existed, this was not the case for coal briquettes need to develop its distribution network. Coal briquette was not able to substitute kerosene as a household fuel and the need for newer household energy shifted to LPG.

There are four reasons why LPG was chosen as the transition household fuel (Budya and Yasir Arofat, 2011). To reduce fuel subsidy, as the LPG subsidy is significantly lower than the kerosene subsidy. LPG is a cheaper fuel than kerosene. As comparison Kerosene production cost is IDR 6,700 while LPG production cost is IDR 4,200(Andadari et al., 2014), kerosene sold as IDR 2,500 LPG sold as IDR 1,800 per liter; LPG is cleaner than kerosene, LPG also cleaner compared with other alternative fuels such as coal briquettes; LPG has the most readily implemented infrastructure to support its use compared to other alternative fuels such as natural gas.

For example, natural gas requires a pipeline infrastructure to be built to deliver gas to the residential sector, LPG can be delivered as bottled gas and therefore can rely on the existing transport infrastructure; The subsidized LPG programme has been successfully implemented in neighbouring countries such as Malaysia and Thailand with similar socio-economic structures as Indonesia. The experiences implementing LPG in Malaysia and Thailand is used as basis to implement in Indonesia.

The LPG transition was successfully implemented due to several factors such as effective governmental policies, an effective business model (with LPG creating a range of business opportunities such as private companies building private depots and filling stations). The perception that LPG is a clean and healthy energy is attracting people to use LPG (Andadari et al., 2014). However, other studies have emphasised that the LPG transition is not effective and has failed to substantially reduce the overall number of energy-poor people, however, it has been effective in alleviating extreme energy poverty, i.e. the percentage of people living under the energy poverty line (Andadari et al., 2014). For example there was only a 2% reduction in the number of energy-poor people, in contrast to a 22% reduction in incidence of expenditure energy poverty (Andadari et al., 2014). The poverty line is according to World Bank standard.

2.5.3. Geothermal transition

Geothermal energy has been identified as a potential alternative energy source in Indonesia since the early 1900s. At that time, the Dutch East Indies, through an early exploration, identified geothermal resources in Kamojang, West Java. The earliest commercial identification of the geothermal energy potential in Indonesia was made in the 1960s with an estimated 200 locations being identified. From the period of 1970-1990 geological mapping and detailed geophysical surveys were performed (Hochstein and Sudarman, 2008). However, the rapid development of geothermal energy only started in 1994 as shown in Figure 2-7. The rapid geothermal transition can be used as a case study that explain the roles of economic and technology policy in energy development.

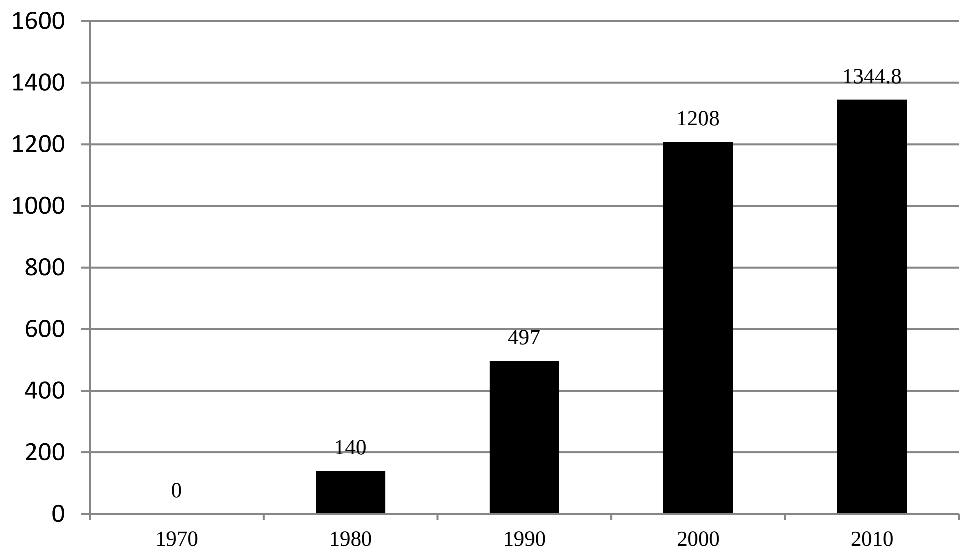

Figure 2-7 Geothermal capacity 1970-2000 in MW (MOEMR, 2014)

Technology innovation system (TIS) (Bergek et al., 2008) is a conceptual theory that believes that innovation occurs in the context of a system which includes technologies, actors and institutions (Jacobsson and Johnson, 2000). TIS places an emphasis on the complex energy system and its relation to the energy business model such as generation, distribution and transmission of energy. Unlike the MLP theory that focusses on multi-level transition, TIS focusses on a single layer where innovation occurs. This focus of TIS theory on innovation is useful in helping explain the development of modern technological developments such as renewable energy. The TIS theory should be able to explain certain challenges and characteristics during the formation and evolution of new technological systems.

Geothermal energy transition can be seen from TIS perspectives. According to TIS theory, the structural component of the geothermal transition involved Actors, Networks and Institutions. In this case the ‘Actor’ is Pertamina, a state-owned company in the energy sector and PLN, a state-owned company in electricity generation. The ‘Network’ is any effort and initiative to gain the knowledge and technical know-how for developing geothermal energy. The ‘Institution’ refers to any policies and regulations that help and support geothermal energy development. An example of network in Indonesia geothermal transition is industry association, university and research agency that cooperate to share the knowledge. INAGA (Indonesia Geothermal Association) for example is a non-profit organization, which functions as a forum of communication, coordination and consultation in order to improve its capabilities, understanding, cooperation and responsibility of the role of geothermal energy development in Indonesia.

TIS theory regards geothermal transition as an innovation process. The innovation is centred on entrepreneurial activities and technical knowledge developments related to geothermal energy. For example, in the geothermal transition, entrepreneurial activities begin with several energy companies creating new business units to develop geothermal energy such as Pertamina Kamojang and Star Energy in the early 1990s. These companies acquire technical knowledge through partnerships with other foreign companies such as Chevron to develop geothermal power plants.

This early knowledge acquisition was driven by various incentives that were given by the government of Indonesia during that period, these ensure that the Independent Power Producer (IPP) investment and continuity is protected. For example, after 1994, the government of Indonesia introduced fixed contracts that allowed the IPP to have contracts for end-to-end electricity services from steam field development, steam production and electricity development as a single package (Hochstein and Sudarman, 2008). This contract model helped attract various energy companies to invest in geothermal energy.

The beginning of the market formulation phase was in early the 2000s. To speed up the geothermal energy transition in 2003, the Geothermal Law (Law no 27 Year 2003) was promulgated. Further, the government of Indonesia developed its national energy policy that promoted the scale-up of the development of geothermal energy. Geothermal energy in Indonesia is prioritized due to its abundance as a resource and its nature as a clean energy source. Although geothermal energy is prioritized, it is still argued that the geothermal transition is too slow. One of the reasons for this is that many geothermal projects are too expensive and require substantial revenues from customers to ensure profitability (Hayes, 2004).

Biodiesel transition can be seen from TIS perspective as an innovation process that involved the entrepreneurial activities, knowledge development to resources mobilization. Biodiesel as innovation of palm oil product is developed as part of palm oil business. Early biodiesel initiative is coming as subsidiary or business unit of a more stable palm oil company. This palm oil company is trying to diversify its product by developing biodiesel.

2.5.4. Energy transition policy

Energy policy in Indonesia is inseparable with energy transition policy. The energy transition policy is an energy policy that focusing on fuel substitution, instead of efficiency or reduction. In Indonesia there several energy transitions policy that are successful, and there is some policy that fail (See Table 2-3). The criteria of a successful transition, in this case, are whether the government initiatives continued and whether the intended energy transition reached an expected target. The reasons for the failure of these transitions are difficult to explain. Most energy transitions in Indonesia are supported by government initiatives. The government provides the incentives, for example, giving out free LPG stoves or coal briquette stoves. The companies that are involved in providing such energy infrastructures are mainly state-owned companies.

Table 2-3 Failed and successful energy transition

Sectors	Fuel	Year	Size	Status
Household	LPG	2007-2010	>50mill HH	Success
Household	Coal Briquette	2006-2007	<1 million HH	Fail
Transport	Palm Oil	2010-2014	>6Mton	Success
Transport	Jatropha Curcas	2006-2008	< 0.1 Mton	Fail
Transport	Sugar Cane	2006-2008	<2 Mton	Fail
Transport	CNG	1980-1985	<1,000 vehicles	Fail

Energy transition can happen over a long time period such as hundreds of years, while some transitions can happen over the duration of only 2-3 years. For example, the Indonesia LPG transition occurred over a period of only 3 years, while other transitions such as natural gas in the Netherlands took approximately 10 years (Sovacool, 2016). Another definition of energy transition is to see energy transition as a geographical process. This approach believes that energy transition processes would be partially shaped by geographical features (Calvert, 2015) such as the availability of geothermal resources, proximity to fossil fuels or distance to industrial centers.

Energy transition in Indonesia might have similar challenges as energy transitions from neighboring countries. Indonesia and Malaysia for example, are the largest palm oil exporters in the world with a combined market share of 85%. Biodiesel transition in Indonesia is following a similar pattern as biofuel transition in Malaysia, with a gradual mandatory blending of biodiesel and alternative vegetation-based fuels to comprise the countries' biodiesel. This similarity occurs for a number of reasons including climate and type of vegetation.

In terms of international pressures, it also has similar patterns of donor intervention and environmental pressure. The recent forest fires, for example, have provided the impetus for the European Union policy to ban biodiesel export from Indonesia and Malaysia. This ban has affected the expansion of palm oil in these countries. Overall, each country has their owned specific challenge in energy transition. Each challenge is unique in every country where the specific policy should be built to ensure its effectiveness. Table 2-4 below describe the comparison of transition challenge in neighboring and peer countries.

Table 2-4 Comparison of transition challenge

Case Study	**Transition Challenge**	**Focus**	**Author**
Malaysia	• Increasing Oil Prices • Donor Interventions • Environmental Pressure	Biofuel	(Hansen and Nygaard, 2014)
Kenya, Tanzania, Ethiopia	• Absorption of technology, • Technical Development	Biofuel	(Murphy, 2001) (Kamp and Bermúdez Forn, 2016)
Philippines	• Increasing Oil Prices • Electricity Market Liberalization	Electricity	(Marquardt et al., 2016)
China	• Dependency on fossil-fuel • Infrastructure unable to catch up	Electricity	(Yuan et al., 2012)
Mexico	• Dominant state-owned company • Market Liberalization	Electricity	(Jano-Ito and Crawford-Brown, 2016)

Another pattern that can be seen is on technical development and innovation, for example in low carbon technology in Philippines, Malaysia, Indonesia the growth of energy transition is dependent on technical innovation (Wong et al., 2016). Wong (2016) explained that based on the applied patent in these countries from 1980-2012 some country is slightly behind in term of science and technology development which lower the growth of low carbon technologies.

Some of the key features that differentiate between energy transition in developed countries and developing countries are in terms of the maturity of social institutions such as government and the roles of state-owned companies. In terms of electricity generation, Indonesia has a similar pattern as the Philippines. The Philippines also has geothermal energy and various sources of energy due to its nature as an archipelago country, it also has many islands that need an individual grid for each island for its electricity supply.

2.6. Discussion

This chapter explores the existing literature of energy transition in order optimize future energy systems. The optimization of energy systems is an important priority which can be understood by taking appropriate approaches. The mitigation of the impact of energy production and consumption such as climate change and air pollution are required to ensure environment sustainability. The literature review above has identified several theories for energy transition. Decision makers within government such ministry office or regional government can choose which models that address their specific concern and adequate for policy evaluation. Literature also specifies that there is not one and only approach or methodology that fits to all requirements for the evaluation of energy policies (Horschig and Thrän, 2017). Energy transition help to provide guidance for the research question in this thesis which is.

"**1) How does the current energy system in Indonesia impact on atmospheric emissions and hence climate change and air pollution?**"

Energy transition help to have better understanding of current impact of energy system in Indonesia. Further, to understand energy systems, it would be useful to capture the trends and characteristics of energy development in Indonesia, including the impact of energy development on the environment for example in terms of human health. From the energy transition point of view, there are several priorities that Indonesia should address such as traditional biomass transition which is the most dominant fuel in domestic sectors (Singh and Setiawan, 2013) and renewable energy transition (Das and Ahlgren, 2010). This condition is related with the research question in this work which addressed in Chapter 2 Energy transition.

"2a) What are the feasible options for future energy transition to more sustainable energy systems for Indonesia? 2b) What the economic, social and political barriers and opportunities for a transition to a sustainable energy system for Indonesia?"

To understand the barriers and opportunities for sustainable energy transition in Indonesia would be based on semi-structured interview for related energy stakeholder in Indonesia such as operative business, government or stakeholder, and research development. This will be explored in Chapter 4 Emission scenario.

"3) How to evaluate the impacts of atmospheric emissions from the energy sector on environmental sustainability?"

The assessment of current every system is important to understand what the current energy mix is and the emissions that results from this which will be addressed in Chapter 3 Emission inventory and Chapter 5 Impact assessment. This will lead to second research question on this work:

4) What will the implications of different scenarios for atmospheric pollution and associated environmental impacts?"

Feasible scenario will be explored in Chapter 4 Emission scenario, while the implication of different scenario will be explored in Chapter 5 Impact assessment.

The focus of this thesis is to assess the impact of the energy transition in Indonesia that can be used as a basis for developing sustainable energy policies in Indonesia. The analysis would consist of both quantitative and qualitative approach of energy transition. Quantitative energy modelling can help to guide large-scale energy planning by evaluating the specific energy transition targets such as renewable energy or clean energy in the energy mix. A quantitative approach will use an emission inventory and scenario analysis to estimate the impact of potential future energy supply and demand. The qualitative approach would be used to generate more comprehensive results by providing various narrative and possible future energy scenario. The qualitative approach would be used to align the process of scenario development. This thesis combining both quantitative approaches and qualitative approaches is expected to provide more comprehensive assessment to support policy formation and implementation.

It should also be noted that the quantitative approach will plug an important knowledge gap in Indonesian energy planning. The quantitative approach will address GHGs and air pollution which currently is not explored in Indonesia. The scenario analysis of energy and environment also lack comprehensive assessment such as impact on human health and agriculture. Therefore, further benefit would be bigger by taking this consideration for benefit the research. Finally, to understand the problem, research and application of energy transition are provided.

The finding and gap in this chapter can be summarized as follows:

- The limited energy transition studies that focus on shifting to clean and renewable energy should be prioritize to minimize the gap that explored in previous study on quantitative impact measurement in terms of GHG emission (Tanoto and Wijaya, 2011), (Kusumadewi and Limmeechokchai, 2015) (Rachmatullah et al., 2007). However, none of the literature described the impact of energy development in terms of integrated GHG and air pollutions in Indonesia.

- The following of energy system characteristics in the residential sectors should be focused which are improved energy access by clean and efficient cooking fuel; and reduce air pollution by switching from traditional biomass.
- Transition to clean and renewable energy is important for sustainable energy development, particularly for people that lives in rural and isolated geographical area in developing countries which typically used traditional biomass energy.
- A better understanding of the impact of energy development Indonesia is needed specially to mitigate both of GHG and air pollution. The integrated policies to be properly implemented to facilitate transition to sustainable energy system.

2.7. Conclusion

In this chapter, the energy transition theory is presented to understand what the main drivers of future energy transitions are likely to be in Indonesia. It is found out that the drivers of energy transition Indonesia are complex involving various stakeholder such as government and state own company. Therefore, governance of energy transition might help Indonesia in designing effective energy transition policy as emphasized in MLP theory. Energy transition theory will be used as guideline in developing feasible emission scenario.

It also found out that geographical condition of Indonesia will play important role in developing energy policy. As archipelagic area with different sources of energy the geographical based energy transition that consider the uniqueness of energy feature in each island is important to be analyzed. The geographical aspect of energy transition will be used in improving emission scenario development.

The basic knowledge described in this chapter includes and introduction to energy transition and characteristic of energy system in Indonesia. To understand the method in this thesis explanation of energy transition theory is presented and related research which will be useful to support this research motivation of using energy transition in Indonesia energy.

Notes:

Chapter 3 Emission inventory to assess the emission of energy system

An emission inventory describes pollutant emissions from all sources such as energy, industry, transport, agricultural sectors that enter into the atmosphere over a given period of time (Boubel et al., 1994). Emission inventories are a useful tool to inform policy making since they quantify the contribution of different sectors to total atmospheric pollution, when coupled with tools that convert emissions into pollutant concentrations and impacts, inventories can be used to assess the benefits of different measures that would mitigate emissions (Tan, 2014). This cycle of emissions, concentrations, impacts and policy response is described by the DPSIR (Drivers, Pressures, State, Impact, Response) framework (Smeets et al., 1999) shown in Figure 3-1 below.

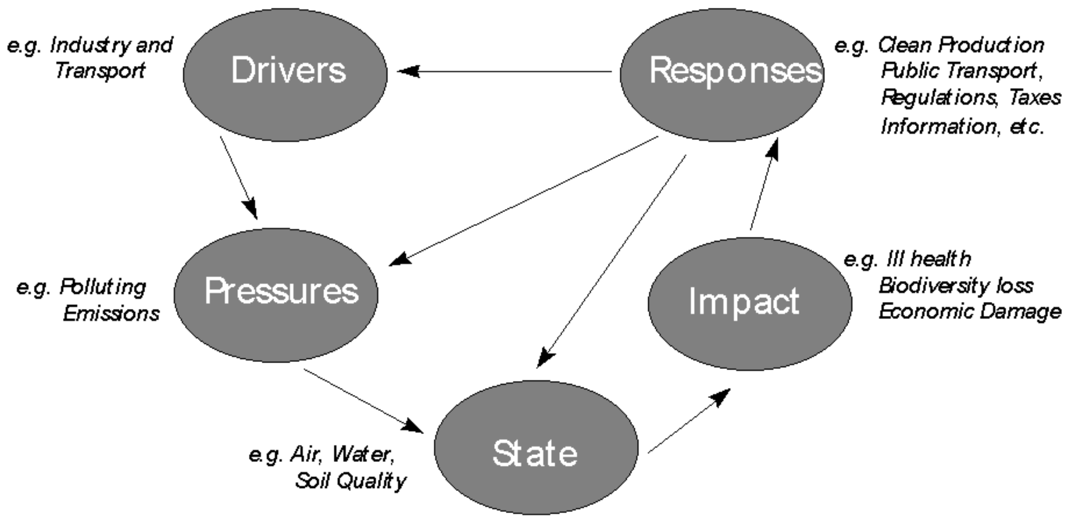

Figure 3-1 DPSIR framework (Smeets et al, 1999)

There are a number of methods that have been developed to established to compile emission inventories. These methods ensure standardization and categorization of emissions data, particularly of emission factors and activity data, thereby ensuring the emission inventory follows good practice and is of high quality. To ensure this standardization and categorization, tools and guidelines for developing emission inventories. These include:- (i) the EMEP/EEA air pollutant emission inventory guidebook, which was designed to facilitate reporting of emission inventories by countries to the UNECE Convention on Long-range Transboundary Air Pollution and the EU National Emission Ceilings Directive (EMEP/EEA, 2019a); (ii) the IPCC Guidelines for National Greenhouse Gas Inventories, which provide methodologies for estimating national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases (IPCC, 2006); and (iii) the Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual (GAP Forum), which provides formulation of methods and assessment of good practice related to the development of effective policies and programs to protect public health and the environment from the harmful effects of atmospheric pollution (Vallack and Rypdal 2019).

These global or regional based emission inventories can be used to provide emissions data for particular countries such as Indonesia (e.g. (Streets et al., 2003) (Zhang et al., 2009) (Kurokawa et al., 2013)); though for such national inventories results will largely be based on internationally available data. Only one emission inventory has been specifically developed for Indonesia (Permadi et al., 2017). This emission inventory covers important emission sources such as fuel combustion used in energy, industry, transportation, residential and commercial sectors, biomass burning, and non-combustion activities in agriculture and waste disposal sectors. The inventory does not cover several important sources such as CH_4 from rice paddies, livestock enteric fermentation, and wastewater. In developing emission inventories, it is important to cover all sources that contribute to atmospheric emissions. In Indonesia, there are a number of activities that are known to significantly contribute to the total air pollution load and that are not always included in emission inventories. For example, activities such as forest fire, biodiesel development and brick kilns and the use traditional biomass for cooking.

3.1. Methodology

Emission inventories will estimate emissions by multiplying an emission factor by an activity rate. An emission factor is the average rate of an emission per unit of activity for a given sector. The activity rate is a measure of the activity causing the emission (e.g. the annual rate of consumption of fuel or amount of industrial product). Emissions can therefore be estimated using the following equation:

$$\boldsymbol{E} = \sum_{\boldsymbol{i},\boldsymbol{j}} \left\{ \boldsymbol{A}_{\boldsymbol{i},\boldsymbol{j}} \times \boldsymbol{EF}_{\boldsymbol{i},\boldsymbol{j}} \right\} \qquad \text{(Equation 1)}$$

E = Annual emission of a given pollutant
A = Activity rate (e.g. fuel consumption, amount of industrial product)
EF = Default emission factor of a given pollutant
i = Fuel type or sub-category of industry
j = Sector type

To develop the Indonesian emission inventory this study has used the Global Atmospheric Pollution Forum (GAP Forum) Air Pollutant Emission Inventory Manual (Vallack and Rypdal, 2019) and associated Excel Workbook (Vallack, 2019). The GAP Forum manual provides guidelines and formulations of methods used to develop emission inventories. The associated Excel workbook provides a structure for inputting activity data and emission factors, annotating datasets, reviewing estimates of intermediate and final emission estimates, and reporting results by sector and pollutant.

The sectors used in the GAP forum manual are the same as those defined by the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) which are energy industries, manufacturing industries and construction, transportation, fugitive emission for fuels (which include solid fuels and oil and natural gas), industrial processes, solvent manufacturing, and agriculture, vegetation and forestry, and waste. For each sector, there are subsectors that describe more detailed activity, for example, under the transport sector there are subsectors for navigation, aviation and road transport. Emissions from each of these sectors are divided into fuel combustion and non-fuel combustion emissions as appropriate. Fuel combustion activities include energy industries, manufacturing industries and construction, transportation, as well as other sectors and other stationary or mobile emissions from fuel combustion.

The GAP Forum emission inventory for Indonesian, has been developed using default emission factors compiled from the IPCC 2006 Guidelines, the EMEP/EEA Emission Inventory guidebook 2016 and, wherever possible, various Indonesian emissions factors to give more representative values of conditions influencing emissions in Indonesia.

The correspondence between emission source categories used in the GAPF-IE tool and those categories used in the 2016 EMEP/EEA Emission Inventory Guidebook and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories is shown on Table 3-1. The numbers are the source category codes used in each compendium.

Table 3-1 Emission inventory categories

GAPF-EI Tool	EMEP/EEA (2016)	2006 IPCC Guidelines
1 Combustion in the Energy Industries	1.A.1 Energy industries	1 Energy (1A Fuel Combustion Activities)
2 Combustion in Manufacturing Industries and Construction	1.A.2 Manufacturing industries and construction	
3 Transport	1.A.3 Transport	
4 Combustion in Other Sectors	1.A.4 Small combustion	
5 Fugitive emission from fuels	1.B Fugitive emission from fuels	1 Energy (1B Fugitive Emissions from Fuels)
6 Industrial Processes	2 Industrial processes and product use	2 Industrial Processes and Product Use
7 Solvent and Other Product Use		
8 Agriculture	3 Agriculture	3 Agriculture, Forestry and Other Land Use
9 Vegetation Fires & Forestry	11B Forest fires	
10 Waste	5 Waste	4 Waste

3.1.1. Key sectors

The key sector that is explored in this study is the energy sector. The energy sector is responsible for energy-related emissions, such as those arising from fuel combustion activities and fugitive emissions from oil and gas production. Energy sector in this thesis shown in Figure 3-2 which include energy consuming and energy transformation activities. Energy sector is very important due to the significant amount of emission that produced from this sector.

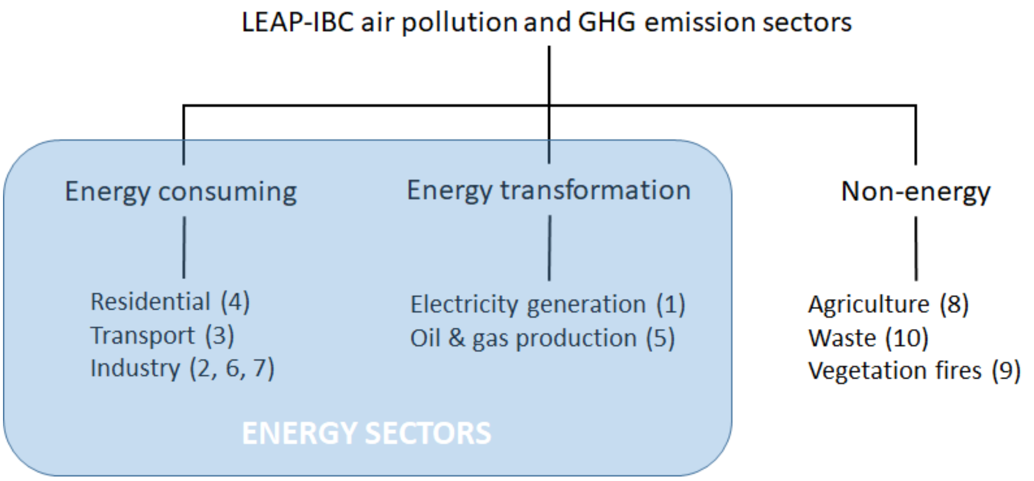

Figure 3-2 Energy related sector analysis

3.1.2. Emission Factors

Emission factors should reflect the emission rate for sectors operating in Indonesia. More accurate assessments of emissions can be achieved by using emission factors specifically developed for Indonesia. For example, emission factors for motorcycle transportation based on the uncontrolled motorcycle emission factor for tier 1 maximum value (EMEP/EEA, 2016) are relatively high (12.8 g/km) when compared with the emission factor (2.22 g/km) used in the Indonesian study by Permadi et al. (2017).

The emission factors used for major emission sources in Indonesia is shown in Table 3-2

Table 3-2 Fossil fuel emission factors used for the major emission sources (kg/TJ)

	Emission Sources	SO_2 [a]	NO_x [b]	CO [b]	NMVOC [b]	NH_3 [b]	PM_{10} [b]	$PM_{2.5}$ [b]	BC [b]	OC [b]	CO_2 [e]	CH_4 [e]
1	**Energy Industries**											
	Sub-Bituminous Coal	896	209	8.7	1.4	0.00028	0.226	0.1	0.002	0.04	96100	1
	Natural Gas	0.25 [c]	89	39	2.6	0.067	0.045	0.045	0.0011	0.0092	56100	1
	Gas/Diesel Oil	138	65	16	0.8	0.101	0.139	0.035	0.012	0.0035	74100	3
	Heavy Fuel Oil	498	142	15	2.3	0.101	1.01	0.78	0.044	0.015	77400	3
2	**Combustion in Industries**											
	Other Bituminous Coal	369	173									
	Sub-Bituminous Coal	896	173	931		0.003	0.98	0.9	0.058	0.92	96100	10
	Natural Gas	0.25 [c]	74	29	23	0.067	0.04	0.04	0.0016	0.013	56100	1
	Gas/Diesel Oil	138	513	66	25	0.007	0.867	0.867	0.49	0.15	74100	3
	Heavy Fuel Oil	498	513	66	25	0.101	0.804	0.804	0.45	0.076	77400	3
	Liquefied Petroleum Gases	0.23	74	29	23	0.067	0.038	0.037	0.0015	0.0015	63100	1
	Kerosene	22	513	66	25	0.005	0.895	0.895	0.5	0.14	71900	3
3	**Civil Aviation**											
	Aviation Gasoline	45	89	26788	424	1.44	0.14	0.14	0.1	0.03	70000	0.5
	Kerosene Jet Fuel	22	89	314	14	1.44	0.14	0.14	0.1	0.03	70000	0.5
4	**Residential**											
	Natural Gas	0.46 [c]	51 [c]	26	1.9	0.01	0.061	0.061	0.0033	0.027	56100	5
	Gas Diesel Oil	138	51	57	0.69	0.007	0.867	0.867	0.49	0.15	74100	10
	Heavy Fuel Oil		51	57	25	0.101	0.804	0.804	0.45	0.076	77400	10
	Liquefied Petroleum Gases	0.23	51	26	1.9	0.01	0.32	0.31	0.01	0.06	63100	5
	Kerosene	22	25 [d]	57	0.69	0.005	0.134	0.129	0.017	0.013	71900	10

Note: [a]Calculated from net calorific value (NCV), sulphur content of fuel (0.5% for sub-bituminous coal: Kaltim Prima Coal (KPC), coal company in Indonesia, and 0.3% for gas diesel: Pertamina, oil and gas company in Indonesia) and sulphur retention in ash (from US EPA,1995); [b]EMEP/EEA (2013) Tier 1 emission factors unless shown otherwise; [c]Kato and Akimoto (1992); [d]Zhang et al. (2000) Average EF for household stoves in China. (For 'vegetal materials and waste', EF = average for wheat and maize residues); [e]IPPC (2006).

The road transport emission factors (g/km) shown in Table 3-3

Table 3-3 Road transport emission factors (g/km)

Emission Sources	NO_x [a]	CO [a]	NMVOC [a]	NH_3 [a]	PM_{10} [a]	$PM_{2.5}$ [a]	BC [a]	OC [a]
Passenger cars (Gasoline)	2.09	18.9	2.41	0.1	0.003	0.003	2	37.7
Motorcycles (Gasoline)	0.375	23.2	2.22	0.002	0.21	0.21	10	6.9
Heavy-duty vehicles (Diesel)	8.92	2.13	0.776	0.003	0.333	0.333	50	0.154
Urban Buses (Diesel)	16.5	5.71	1.99	0.003	0.909	0.909	50	0.154

Note: [a]Permadi et al (2017)

Biomass fuel emission factors used for the major emission sources is shown in Table 3-4.

Table 3-4 Biomass fuel emission factors (kg/TJ) used for the major emission sources

		1	2	3	4	5	6	7	8	9	10	11
	Emission Sources	SO_2 [a]	NO_x [b]	CO [e]	NMVOC [e]	NH_3 [d]	PM_{10} [e]	$PM_{2.5}$ [e]	BC [h]	OC [h]	CO_2	CH_4 [k]
1	**Energy Industries**											
	Wood (Charcoal Production)	53	12.3 [d]	6453 [d]	2187d	0.37	2.6 [h]	2.6 [h]	0.2	1.3	N/A	893
2	**Combustion in Industries**											
	Wood (Brick Kilns)	53	91	570	300	1.29	2.14	2.1	0.59 [e]	1	N/A	30
	Vegetal Material & Waste (Brick Kilns)	67	91	570	300	0.91j	1.72	1.68	0.47 [e]	1	N/A	30
3	**Residential**											
	Wood	20 [b]	73 [f]	4260 [f]	600	1.29	3.9 [h]	3.12 [a]	0.62	1.78	N/A	300
	Charcoal	23 [c]	91 [g]	4567 [d]	600	0.97	2.38 [i]	2.28 [a]	1.19	0.85	N/A	300

Note: [a]Reddy and Venkataraman (2002); [b]Smith et al (2000); [c]Kato and Akimoto (1992); [d]Derived from Bertschi et al. (2003) for earthen charcoal-making kilns (in Zambia); [e]EMEP/EEA (2013) Tier 1 emission factors; [f]Zhang et al. (2000) Average EF for household stoves in China. (For 'vegetal materials and waste', EF = average for wheat and maize residues); [g]Derived from Bertschi et al. (2003) for charcoal cooking fires; [h]Bond et al (2004); [i]Smith et al (2000); [j]Li et al (2016) - Value of 0.91 is the mean for three types of biomass briquette in traditional stove (use 0.17 for advanced stove); [k]IPPC (2006)

Emission factors used for the industrial process and agriculture sectors emission sources is shown in Table 3-5. The rice, soya and maize emissions are from the plantation of the crop alone, the emissions are not including crop residue open burning.

Table 3-5 Emission factors (kt/t) used for the industrial process and agriculture sectors emission sources

		1	2	3	4	9	5	6	7	8	10	11
	Emission Sources	SO_2 [a]	NO_x [a]	CO [a]	NMVOC [a]	NH_3 [a]	PM_{10} [a]	$PM_{2.5}$ [a]	BC [a]	OC [a]	CO_2 [c]	CH_4 [c]
1	**Industrial Process**											
	Portland cement production						0.22	0.12			494.0 [a]	
	Lime production						3.50	0.70			750.0 [a]	
	Asphalt for road paving				0.02		3.00	0.50				
	Ammonia	0.03 [b]	1.00	0.10	4.70 [b]	0.01					3273.0	
	Carbon black	22.00	15.00	3.00	0.70		0.27	0.24	0.02		2620.0	
	Urea					2.50	1.20	0.90	0.02			
	Pig iron production	0.04	0.008	0.027			1.00	0.50	0.00	0.00	1600.0	
	Aluminium production	4.50	1.00	120.00			0.70	0.60	0.01		1650.0	
	Lead smelting (primary)	320.00					0.45	0.23			520.0	
	Zinc smelting (primary)	1000.00					0.17	0.13			1720.0	
	Kraft pulping + Alkaline soda pulping	2.00	1.00	5.50	2.00		0.80	0.60	0.02			
	Beer				0.035							
	Sugar (Raw)				10.00							
	Polyester processing				50							
	Polyvinylchloride				10							
	Industrial Paint				800							
	Decorative Paint				230							
2	**Agriculture**											
	Dairy cattle					28.7						5
	Other cattle					9.2						2
	Buffalo					9						5
	Pigs					6.5						5
	Sheep					1.4						0.2
	Goats					1.4						0.22
	Horses					14.8						2.19
	Mules and asses					14.8						1.2
	Poultry					0.48						0.02
	Ammonium sulphate - Low soil pH		0.026			0.013						
	Other complex NK, NPK fertilizers		0.026			0.037						
	Ammonium solutions		0.026			0.125						
	Rice	0.3	2.4	58.90	6.3	2.4	5.8	5.5	0.5	3.3		2.7 [e]
	Soya	0.48	2.3	66.70	0.5	2.4	5.7	5.4	0.5	3.3		2.7 [e]
	Maize	0.2	1.8	38.80	4.5	2.4	6.2	6	0.75	3.3		2.7 [e]
	Tropical/subtropical forest (primary)	0.57 [d]	2.45 [d]	104 [d]	8.1 [d]	1.3 [d]	10.5 [d]	9.1 [d]	0.66 [d]	5.2 [d]		6.8 [d]
	Uncontrolled waste incineration plant	1.7	1.8	0.7	0.02		13.7	9.2	0.322			0.06
	Open burning Waste	0.5 [e]	4.9 [e]	38 [e]	7.5 [e]	1.12 [e]	11.9 [e]	9.8 [e]	0.65 [e]	5.27 [e]		3.66 [e]

Note: [a]EMEP/EEA (2013); [b]US EPA (1995); [c]IPCC (2006); [d]Value given by Andeae and Merlet (2001) for agricultural residues; [e]Akagi et al (2011)

Emission factors used for the major fugitive emission sources is shown in Table 3-6

Table 3-6 Emission factors (kg/kt) used for the major fugitive emission sources

Emission Sources	SO_2	NO_x	CO	NMVOC[b]	BC	CO_2[b]	CH_4[b]
Fugitive Fuel Emissions							
Oil Well Drilling				0.7[a]			0.325[a]
Venting				584		129	978
Flaring (BC emissions only)					0.51[c]		
Flaring (Other emissions)				28.6		55492	33.8
Other fugitives (Onshore)				420		24.9	343
Other fugitives (Offshore)				0.847		0.049	0.675
Marine vessels				71		0.65	7.1
Rail tank cars & tank trucks				286		2.63	28.6
Pipeline Transport				62		0.56	6.2
Oil Refinery (Throughput)	0.92[b]	0.06[b]	0.09[b]	1.49			0.012
Refinery dispatch station				489.805[d]			
Transport and depots				60[d]			
Service station				2013.646[d]			
Natural Gas Production				8.45		36.7	77.2
Surface mines: mining activities							0.8

Note: [a]Default value from EMEP/EEA (2013); [b]IPCC (2006); [c]McEwen and Johnson (2012); [d]EMEP/EEA (2016). Emission factors unit is kg/kt except for Oil well drilling (tonnes/well drilled), Oil refinery, Coal mining (kg/t) and Natural gas production (kg/TJ).

EF for refinery dispatch station is calculated using formula

$$\boldsymbol{E} = \mathbf{9} \times \boldsymbol{TVP} \div \mathbf{0.739} \qquad (14)$$

EF for service station is calculated using formula

$$\boldsymbol{E} = \mathbf{37} \times \boldsymbol{TVP} \div \mathbf{0.739} \qquad (15)$$

Where

$$\boldsymbol{TVP} = \boldsymbol{RVP} \times \mathbf{10}^{\boldsymbol{AT+B}} \qquad (16)$$

$$\boldsymbol{A} = \mathbf{0.000007047} \times \boldsymbol{RVP} + \mathbf{0.0132} \qquad (17)$$

$$\boldsymbol{B} = \mathbf{0.0002311} \times \boldsymbol{RVP} - \mathbf{0.5236} \qquad (18)$$

TVP = True Vapor Pressure

RVP = Reid Vapour Pressure (kP) = 80 kpa

T = Temperature (°C) = 15 °C

3.1.3. Activity data for Indonesia

The activity data used in this Indonesian emission inventory are mainly taken from the Government of Indonesia data sources such as the Indonesia National Statistics Agency (INS) and from various Indonesian ministries (i.e. Ministry of Energy, Ministry of Transportation, Ministry of Agriculture, and Ministry of Health) (MOEMR, 2017). Where nationally-derived data were unavailable, activity data were obtained from international sources such as the IEA (International Energy Agency) (IEA, 2014b), World Bank (World Bank, 2014), FAOSTAT (FAO, 2014) and GFED (Global Fire Emission Database) (Randerson et al., 2015). However, there were several activity data that were not available, for example, currently there are no data on brick kilns fuel consumption available in Indonesia. Where important activity data did not exist, methods were developed in this study to estimate activity based on data collected in Indonesia. The government available and official data is 2010, there are many versions of the official data, therefore based on both factor the data that used is 2010. The limitation of this emission inventory database is on the source of activity data that used.

a. Combustion in the energy industries

Combustion in the energy industry can be divided into three parts: electricity generation, petroleum refining and manufacture of solid fuels and other energy. This section covers all combustion in these energy industries including ‘own use’ combustion (fuel for own on-site use) but does not include auto-production of electricity by the manufacturing industry. Energy producing industries ‘own use’ of energy, such as for oil refining, oil and gas extraction and coal mining are termed ‘other own use’. Based on IEA data, the fuel consumption for power generation, petroleum refining and ‘other own use’ in 2010 is shown in Table 3-7.

Table 3-7 Combustion in the energy industries in Indonesia in 2010 (IEA, 2014)

Energy Industries	**Fuel**	**Value (ktoe)**
Electricity	Sub-Bituminous Coal	12,590
	Natural Gas	6,995
	Gas/Diesel Oil	6,021
	Heavy Fuel Oil	2,207
Petroleum Refining	Natural Gas	840
	Refinery Gas	716
	Gasoline type Jet Fuel	54
	Gas/Diesel Oil	1,347
Manufactures Solid Fuels and Other		
Oil and Gas Extraction	Natural Gas	5,071
Liquefaction / Regasification	Natural Gas	3,829
Charcoal Production	Wood	1,107
Auto-production of electricity	Sub-Bituminous Coal	6,142
	Natural Gas	1,647
	Gas/Diesel Oil	260
	Unspecified primary solid biomass	41

Note: ktoe = kilotonnes of oil equivalent

'Auto-production of electricity' is defined as private electricity production in the manufacturing industry and is that electricity that is used for the industries own operation and not for sale to the public. In developing an emission inventory, auto-production of electricity is often grouped as combustion in the manufacturing industry. However, due to the significant amount of electricity generated from this source in Indonesia, auto-production of electricity is also included in Table 3-2.

b. Combustion in manufacturing industries

The fuel consumption for manufacturing industries in 2010 for Indonesia, taken from International Energy Agency (IEA) data, is shown in Table 3-8.

Table 3-8 Combustion in manufacturing industries in Indonesia in 2010 (IEA, 2014)

Manufacturing Sectors	**Fuel**	**Value (ktoe)**
Iron and Steel	Natural Gas	493
	Gas/Diesel Oil	264
	Heavy Fuel Oil	450
Non-ferrous Metals	Coking Coal	37
	Other Bituminous Coal & Anthracite	206
Non-metallic Minerals	Sub-Bituminous Coal	3,315
	Gas/Diesel Oil	802
	Heavy Fuel Oil	349
Chemicals	Natural Gas	2,505
	Gas/Diesel Oil	549
	Heavy Fuel Oil	278
Mining and Quarrying	Gas/Diesel Oil	1,198
	Heavy Fuel Oil	79
Construction	Gas/Diesel Oil	427
Non-specified Industry	Other Bituminous Coal & Anthracite	195
	Sub-Bituminous Coal	8,153
	BKB (Brown coal briquettes)	38
	Natural Gas	8,788
	Liquefied Petroleum Gases	139
	Kerosene	138
	Gas/Diesel Oil	586
	Heavy Fuel Oil	253
	Other Petroleum Products	2,619
	Primary solid biomass	6,238

The following sections explain the derivation of fuel consumption data for which there are no existing estimates for Indonesia.

c. Brick kilns

Currently there are no data on brick/tile kilns fuel consumption available in Indonesia. To estimate the fuel consumption in traditional kilns, the following equation was used:

$$\boldsymbol{A} = \boldsymbol{T} \times \boldsymbol{W} \times \boldsymbol{C} \qquad \text{(Equation 8)}$$

A = Fuel consumption in brick/tile kilns

T= Total production (number of bricks or tiles)

W= Brick/tile weight

C= Consumption of energy per brick/tile (i.e. energy consumption per kg x brick/tile weight)

The following data for application of equation 4 were obtained from the Ministry of Industry (MOI, 2010). Brick/tile production data were based on the selling price of bricks and tiles. The observation and unit measurement such as dimension and weight is taken in Cirebon, Indonesia in November 2016. Cirebon is selected as it located in the most densely populated province in Indonesia as shown in Figure 3-3. Cirebon also centre of production traditional brick and tile kilns.

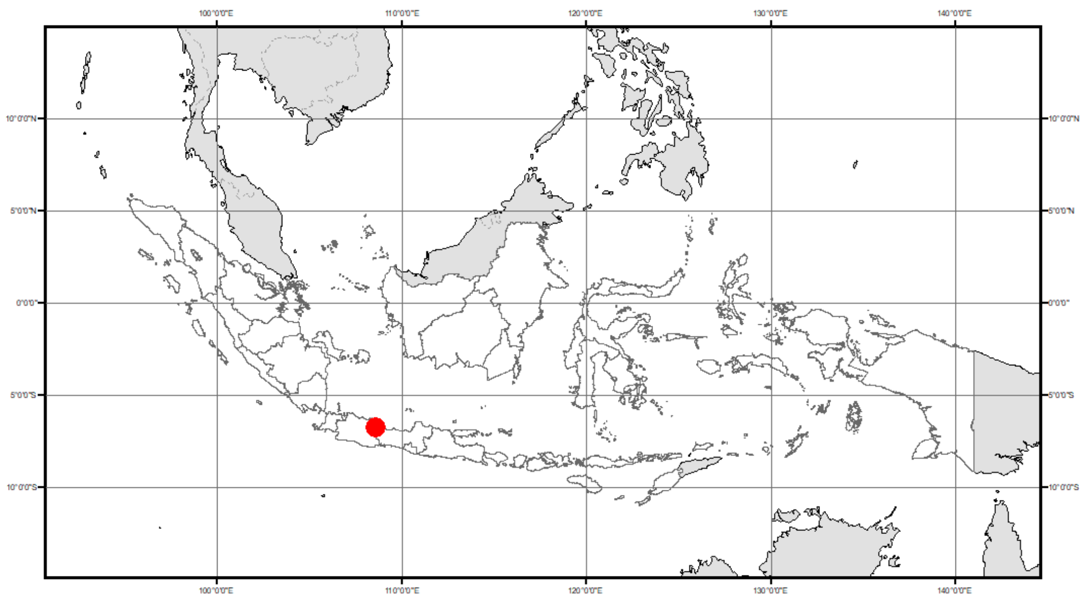

Figure 3-3 Cirebon position in the map

The observation also takes unit measurement such as dimension and weight. In Indonesia, traditional brick kilns usually also produce tiles at the same location. The main difference is the preferred fuel for manufacture of bricks is rice husks while tile kilns use wood. The type of firing used is open kilns and the bricks and tiles are formed using hand moulds and dried as shown in Figure 3-4.

Figure 3-4 Brick kilns dry process showing rice husks as fuel

The firing of bricks (Figure 3-5) usually takes 3-5 days whereas the firing of tiles (Figure 3-6) usually takes only 2-3 days.

Figure 3-5 Brick kilns firing process

Figure 3-6 Tile kilns firing process

The summary of these data that are required to estimate the energy consumption for the production of bricks/tiles in Indonesia in 2010 are described in Table 3-9.

Table 3-9 Traditional brick and tile kiln production data used to estimate fuel consumption for this industry in Indonesia in 2010

Component	**Brick Kilns**	**Tile Kilns**	**Note**
Dimension	5 cm x 10 cm x 20 cm	1.5 cm x 24 cm x 34 cm	Own observation
Weight	1000 g	2500 g	Own observation
Energy consumption	2.5 MJ/kg	1.9 MJ/kg	(Rajarathnam et al., 2014)
Fuel	Rice Husk	Wood	Own Observation
Price (IDR)	330	1,500	Tile (Nugroho, 2006) Brick (Roachanakanan and Nichols, 2009).
Total Production Value (million IDR)	194	418	Ministry of Industry
Total Production Unit (million bricks)	747	278	Calculated

Application of this methodology with the data provided in Table 3-4 results in an estimate of energy consumption of 44.7 ktoe for brick kilns and 31.5 ktoe for tile kilns used in traditional kiln production in Indonesia for 2010. This result is primary data for brick kilns which are from the field survey.

d. Transport

There are two methodologies that can be used to estimate the emission from Indonesian transportation sectors. The first, ‘simple’ method is based on fuel consumption only, and this method was used to derive emissions of SO_2, CH_4 and CO_2 from all transport subsectors and the remaining pollutants from the navigation and aviation subsectors. The second, more 'detailed', method was used for determining the remaining pollutant emissions for road transport. This required an estimate of the activity rate associated with road transport, which was estimated as the distance travelled per vehicle according to different vehicle categories. This different vehicle category is based on engine size, fuel consumption and emission factor. To apply the fuel consumption methodology, fuel consumption data were taken from IEA 2010 (Table 3-10). The fuel consumption methodology is use a simple methodology.

Table 3-10 Transportation sectors, associated fuel type and fuel consumption in Indonesia in 2010.

Transportation Sectors	Fuel	Value (ktoe)
Navigation		1.97
Aviation	Aviation Gasoline	1.63
	Kerosene type Jet Fuel	2,825.94
Road Transport	Motor Gasoline	18,367.62
	Gas/Diesel Oil	9,609.08

Estimation of emission (E) using the more 'detailed' method used the following equation:

$$\boldsymbol{E} = \sum_{\boldsymbol{i}} \{\boldsymbol{NV_i} \times \boldsymbol{ADT_i} \times \boldsymbol{EF_i}\} \qquad \text{(Equation 9)}$$

NV = Number of registered vehicles

i = Vehicle types

ADT = Annual distance travelled

EF = Emission Factor

In the more 'detailed' methodology, data describing the number of vehicles by vehicle type were obtained from the Indonesia Central Bureau of Statistics for 2010 (CSA, 2017) and data for average distance travelled per vehicle from (Sukarno et al., 2016) (Table 3-11).

Table 3-11 Data required for application of the detailed method to estimate emissions from Indonesian transport (CSA, 2017) and (Sukarno et al, 2016)

Fuel Type	Vehicle class	Number of vehicles	Average distance travelled per vehicle (km/year)
Gasoline	Passenger cars	8,891,041	10,037
Gasoline	Motorcycles (2-stroke)	61,078,188	7,847
Diesel	Heavy-duty vehicles	4,687,789	44,347
Diesel	Urban Buses	2,250,109	44,347

e. Combustion in other sectors

The activity data for combustion in other sectors such as commercial, residential and agriculture is taken from IEA (2010) as shown in Table 3-12.

Table 3-12 Combustion in other sectors

Sectors	Fuels	Value (ktoe)
Commercial	Gas Works Gas	132
	Liquefied Petroleum Gases	127
	Kerosene	114
	Gas/Diesel Oil	838
	Wood	202
Residential	Gas Works Gas	19
	Liquefied Petroleum Gases	4041
	Kerosene	2070
	Wood	46292
	Charcoal	337
Agriculture/Forestry/Fishing	Gas/Diesel Oil	2965
Non-Specified Sectors	Heavy Fuel Oil	262

f. Fugitive emissions from fuels

The 2010 activity data associated with fugitive emissions from the energy industry in Indonesia are taken from Ministry of Energy (MOEMR, 2017) and shown in Table 3-13. Fugitive emission defined as intentional or unintentional release of greenhouse gases may occur during the extraction, processing and delivery of fossil fuels to the point of final use.

Table 3-13 Activity data required for calculating fugitive emissions from fuels

Activity		Activity rate	Activity type and units
Oil well drilling		64	No. of wells drilled/year
Production of Conventional Oil	Venting	46,574	Crude oil production (kt/yr)
	Flaring (BC emissions only)	8,167,000	Volume of gas flared as 1000s of cubic metres per year
	Flaring (Other emissions)		Crude oil production (kt/yr)
	Other fugitives (Onshore)	27,385	Crude oil production (kt/yr)
	Other fugitives (Offshore)	19,188	Crude oil production (kt/yr)
Loading onto tankers	Marine vessels	36,648	Crude oil loaded (kt/yr)
	Rail tank cars & tank trucks	803	Crude oil loaded (kt/yr)
Pipeline transport		9,121	Mass oil transported (kt/yr)
Throughput of crude oil		62,434	(kt/year)

Natural Gas Production	3,129,256	(TJ gas/year)
Coal Mining	186,314	(kt coal mined per year)

g. Industrial processes

The 2010 activity data for industrial processes in Indonesia are taken from the Ministry of Industry (MOI, 2010) and shown in Table 3-14.

Table 3-14 Industrial process activity data

Sectors	**Fuels**	**Value (kt)**
Mineral Products	Portland cement production	38,000
	Lime production	30,667
	Asphalt for road paving	900
Chemical	Ammonia	5,275
	Carbon black	128
	Urea	8,000
Metal	Pig iron production	1,533
	Aluminium production	236
	Lead smelting (primary)	22
	Zinc smelting (primary)	16
Pulp and Paper	Kraft pulping and Alkaline soda pulping	211
Food and Drink	Beer (thousand hectolitres)	2,000
	Sugar (raw)	2,600
Solvent and Other Product Use	Industrial Paint	275
	Decorative Paint	412
	Polyester processing	500
	Polyvinylchloride	550

h. Agriculture

Atmospheric emissions from agriculture occur from several different agricultural ‘activities’ such as livestock husbandry, rice cultivation, agriculture residue burning and fertilizer application. Each of these has specific activity data and emission estimation methods as described below.

Emission (E) estimation from livestock is calculated with the following equation

$$\boldsymbol{E} = \sum_{\boldsymbol{i}} \{ \boldsymbol{P_i} \times \boldsymbol{EF_i} \} \qquad \text{(Equation 10)}$$

P = Population of livestock

i = Livestock category

EF = Emission Factor

Data describing the number of livestock in Indonesia in 2010 were taken from the Indonesian Ministry of Agriculture (MOA, 2012) and are shown in Table 3-15.

Table 3-15 Livestock activity data

Sectors	**Type**	**Value**	**Units**
Animal	Dairy cattle	488	Thousands of animals
	Other cattle	13,582	Thousands of animals
	Buffalo	2,000	Thousands of animals
	Pigs	7,477	Thousands of animals
	Sheep	10,725	Thousands of animals
	Goats	16,620	Thousands of animals
	Horses	419	Thousands of animals
	Poultry	1,393,926	Thousands of animals

Rice cultivation processes in Indonesia can be described as either irrigated or upland (rain-fed) cultivation, these different rice cultivation practices will have different levels of emission associated with them. The estimate of emission (E) from rice cultivation is calculated using following equation.

$$\boldsymbol{E} = \boldsymbol{P} \times \boldsymbol{C} \times \boldsymbol{B} \times \boldsymbol{S} \times \boldsymbol{H} \qquad \text{(Equation 11)}$$

P= Annual harvested area
C= Cultivation period
B= Baseline emission factor for continuously flooded fields without organic amendments
S= Scaling factor to account for the differences in water regime during cultivation period
H= Scaling factor to account for the differences in water regime in the pre-season before the cultivation period

Irrigated fields are defined as being flooded for a significant time period during which the water regime is fully controlled. Upland fields are rain-fed and are never experience long-term flooding; as such, in upland fields CH_4 emissions are zero even with organic amendments. Based on 2010 Indonesian National Statistics Data, there are 4,893,128 ha of irrigated rice cultivation and 3,109,424 ha of upland rice cultivation. The period of rice cultivation is 120 days.

Agriculture residue burning emissions are produced from the open burning of agriculture crop residue wastes in the field. The estimate of emission from agriculture residue burning is following this equation.

$$E = \sum_i \{ P_i \times N_i \times D_i \times B_i \times EF_i \} \qquad \text{(Equation 12)}$$

P= Annual crop production

N= Crop-specific production-to-residue ratio

D= Dry matter fraction

B= Percentage of burned residues

EF= Emission Factor

i= Crop type

Annual production for a range of crops in 2010 was taken from the Indonesia Central Statistics Agency (CSA, 2011). Rice production was 66,469 kt followed by Maize production of 18,328 kt and Soya production of 907 kt.

Emission estimation from fertilizer application was calculated using the standard equation (1) assuming that the combustion efficiency is 1.0. The N, D, B value given by Andeae and Merlet (2001) for agricultural residues The activity data of fertilizer application is taken from FAOSTAT consumption data (FAOSTAT, 2017b). In 2010, the consumption of ammonium sulphate was 731 kt, NPK complex consumption was 1,804 kt and urea consumption was 5,131 kt.

i. Waste

There are several different types of waste that lead to atmospheric emissions. The most important are waste incineration, including open burning of municipal solid waste (MSW), ammonia emissions from human excreta, CH_4 emissions from MSW in landfill and CH_4 emissions from domestic wastewater treatment and discharge.

Waste Incineration - Waste incineration data for 2010 were taken from the Waste Atlas (D-waste, 2015) and the estimation of open burning of waste was taken from Indonesian Domestic Solid Waste Statistics (MOEF, 2008). The estimated quantity of MSW incinerated by open burning in 2010 is 2,800 kt.

Human Excreta - Latrines in this section are defined as a simple ‘dry’ toilet built outside the house over a hole dug in the ground or a concrete reservoir. The data on population who use latrines is taken from Indonesia National Office Statistics in 2010. There were 19,197,000 people using latrines in 2010 which is assumed to be the rural population only. The estimate of NH_3 emission from latrines employed the standard equation (1).

Landfill - The population whose waste as collected in 2010 (127 million) comes from the Indonesia National Office Statistics (CSA, 2011). Per capita MSW generation rate (0.7 ton/capita/year) is taken from Indonesia Ministry of Environment Data (MOEF, 2012). The estimation CH_4 emission from landfill is using following equation.

$$E = P \times GR \times MSW \times MCF \times DOC \times DOC_f \times F \qquad \text{(Equation 13)}$$

P= Number of populations whose waste is collected

GR= Per capita MSW generation rate

MSW= Fraction of MSW disposed to solid waste disposal sites

MCF= Methane correction factor

DOC= Degradable organic carbon

DOC_f= Fraction DOC dissimilated

F= Fraction of CH_4 in landfill gas

Domestic wastewater treatment - Emission from wastewater covers CH_4 emissions from domestic wastewater treatment and discharge. The estimate of CH_4 emissions from domestic wastewater treatment and discharge is calculated with the following equation.

$$E = \sum_{i,j} \{P_{i,j} \times BOD \times B_{i,j} \times MCF_{i,j}\} \qquad \text{(Equation 14)}$$

P= Number of populations

i= Income Group (Rural, Urban high income, Urban low income)

j= Type of treatment system utilization (Latrine, Septic Tank, Untreated)

BOD= Degradable organic component

B= Maximum methane producing capacity

MCF= Methane correction factor

Activity data and treatment type by income group for wastewater emission is taken from National Office Statistics 2010 (CSA, 2011). Activity data for wastewater emissions are described in Table 3-16.

Table 3-16 Activity data for wastewater treatment for Indonesia for 2010.

Income group	**Fraction of population**	**Type of treatment system**	**Utilization of treatment split**
Rural	0.46	Latrine	0.214
	0.46	Septic tank	0.425
	0.46	Anaerobic reactor or deep lagoon	
	0.46	Aerobic treatment plant	
	0.46	Untreated (Sea, river or lake discharge)	0.361
Urban high income	0.27	Latrine	0.081
	0.27	Septic tank	0.751
	0.27	Anaerobic reactor or deep lagoon	
	0.27	Aerobic treatment plant	
	0.27	Untreated (Sea, river or lake discharge)	0.168
Urban low income	0.27	Latrine	0.081
	0.27	Septic tank	0.751

	0.27	Anaerobic reactor or deep lagoon	
	0.27	Aerobic treatment plant	
	0.27	Untreated (Sea, river or lake discharge)	0.168

j. Forest fire

Forest fires are major sources of trace gases and aerosol that significantly influence the chemical composition of the atmosphere emission through direct emissions and secondary chemical and physical processes. Forest fire released variety of emission such as include GHGs, photochemically reactive compounds, and particulate matter (Urbanski et al., 2008).

To estimate the emission (E) from forest fire, the following equation is used.

$$\boldsymbol{E} = \boldsymbol{P} \times \boldsymbol{B} \times \boldsymbol{EF} \qquad \text{(Equation 15)}$$

P= Annual area burnt
B= Biomass consumption

Forest fire annual burnt area data is taken from GFED (Global Fire Emission Database) v4 (Randerson et al., 2015). Based on GFED data the annual burnt area for tropical forest in Indonesia in 2010 is 383,000 ha.

It is important to note that area of forest fires in Indonesia fluctuates widely from year to year (Figure 3-7). The extent of forest fire used in this inventory, based on 2010 data, is relatively low at 383,000 ha. However, in 2009 the burnt area was 2,090,800 which is 5.4 times higher, and in 2015 the area burnt was 3,578,900 which is 9.3 times higher. This must be borne in mind when assessing the significance of forest fire emissions within the context of the national emission inventory for 2010 reported below. In general, 2010 is set as baseline to ensure the completeness of data for analysis. The forest fire assumed to cover peat soil burning.

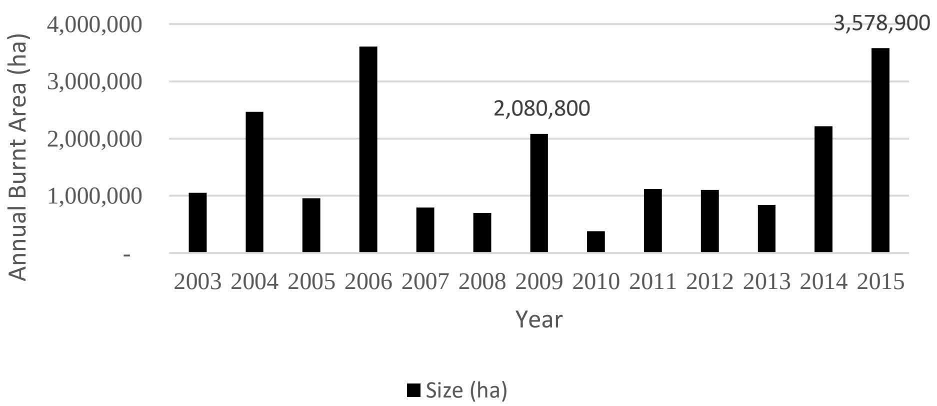

Figure 3-7 The annual burnt area (in ha) associated with Indonesian forest fires from 2003 to 2015. Data obtained from the GFED database (Randerson et al., 2015).

3.2. Uncertainty

An uncertainty analysis of the emission inventory for Indonesia was carried out based on the IPCC (2006) error propagation methodology in which uncertainty is expressed as a 95% confidence interval (i.e. there is a 95 % probability that the actual value is within the interval defined by the confidence limit). The default sources of emission factors used in the analysis (EMEP/EEA, 2016 and IPCC, 2006) include the lower and upper limits of the 95% confidence interval, defined by the 2.5 percentile and 97.5 percentile of the cumulative distribution function of the estimated EF. Key uncertainty coming from the use of default EFs for the sources elsewhere to estimate emissions for those in Indonesia and that can not be calculated by any approach in the thesis.

For certain emission factors taken from sources other than EMEP/EEA or IPCC, uncertainties are expressed as ± the standard deviation (SD) of the mean value. The upper and lower 95% confidence intervals were then taken to be ± twice the SD (expressed as percent of the emission factor). Uncertainty in the activity data was also taken into account in this analysis, the higher end of the uncertainty ranges given in EMEP/EEA (2016) for non-OECD countries being assumed to apply, that is, ±10% for both IEA energy statistics and UN databases.

For other sources of activity data, the IPCC (2006) indicate an uncertainty range of 30-100%. The top end of this range is applied, interpreted as a 2-fold uncertainty (i.e. +100% -50%), to the quantity of municipal solid waste (MSW) generated (activity data for CH_4 from landfill), the amount of MSW open-burnt, and for road transport, the vehicle kilometres travelled (VKT) by each type of vehicle. All uncertainty bounds around the central values were first converted into percentages (+x%, -y%) before being combined, the upper and lower bounds being calculated separately. Where the uncertain quantities were to be combined by multiplication (e.g. EF x activity rate), the combined uncertainty was calculated as the square root of the sum of the squares of the individual % uncertainties. This is the ‘root-sum-squares’ method - also termed the ‘Rule B’ method in Chapter 3 of the IPCC (2006) Guidelines.

The IPCC (2006) ‘Rule A’ method was applied where the uncertain quantities were combined by addition, such as emissions of a particular pollutant species from each of several different fuels used within the same sector. In the ‘Rule A’ method, the individual % uncertainties are first weighted according to each fuel’s contribution to the total emission of the species for that sector, with the ‘root-sum-squares’ of the weighted percentages then producing the combined uncertainty. As an emission inventory is essentially the sum of products of EFs and activity data, Rules A and B were used repeatedly to estimate the combined uncertainty in total emissions for each pollutant species. Lastly, the combined percent uncertainties calculated for the upper and lower bounds around the totals were converted into absolute quantities for inclusion in the results.

3.3. Results and discussion

3.3.1. Emission estimates for Indonesia

The results of emission inventory for Indonesia indicates that energy related sectors contribute the most pollutants of CO_2, SO_2, NO_X and $PM_{2.5}$ as shown inFigure 3-8 below.

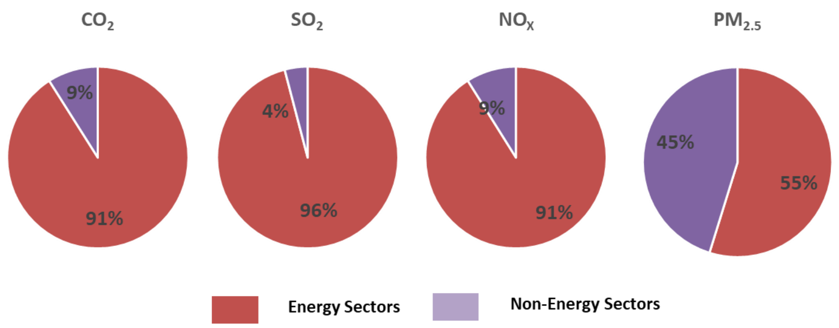

Figure 3-8 Contribution of energy sectors in Indonesia

SO_2 emissions are mainly from road transportation sectors. However, for the other pollutants, coal-based power stations including public electricity generation and auto-production of electricity and industry sector the three major sources of emissions in Indonesia. Road transportation is responsible for the majority of CO, NOx and NMVOC emissions, the residential sector for a sizable contribution to CO and NMVOC emissions and forest fires, at least in 2010, being the third largest source of CO emissions. However, the fact that in 2010 the area of forest burnt was atypically low means that emissions from forest fires in this year also appear to be relatively low. This source of emissions would have been much more significant if, for example, data for 2015 had been used, when a much greater area of forest was burnt (Pribadi and Kurata, 2017).

The main emission sources in Indonesia reflect the country's energy system which is dependent on the use of fossil fuel and the use of wood as a traditional biomass fuel in domestic cooking. Key sub-sectors on which policies or mitigation strategies should be focussed in order to control emissions of that pollutant need to be identified. In general, transportation (CO, NO_x, NMVOC), the residential sector (CO, NMVOC) and vegetation fires (CO) are the three major sources of emission in Indonesia.

The transport sector is the biggest source of SO_2 accounting for 33% of total SO_2 emissions. The use of biomass as a cooking fuel is the primary contributor of residential sector emissions. The combustion of coal, biomass and diesel oil is a characteristic of the energy system in Indonesia and use of these fuels is thus a major source of emissions in this country. A mitigation strategy for energy and environment policy in Indonesia should consider the substitution and transition to cleaner fuels.

Figure 3-9 shows the total emissions for each pollutant investigated by sector for Indonesia for 2010. This shows that road transportation, the residential sector and vegetation fires are the three major sources of air pollutant emissions in Indonesia. Overall, transportation sector contributed most to the pollutant emissions considered in this study (especially CO, NO_x and NMVOC) with a 41% share of total emissions, as shown in Figure 3-9. The residential sector follows as the second most polluting sector. The third biggest pollutant source sector was industry sector. From the energy system perspective, consumption of energy produced more emissions than energy supply.

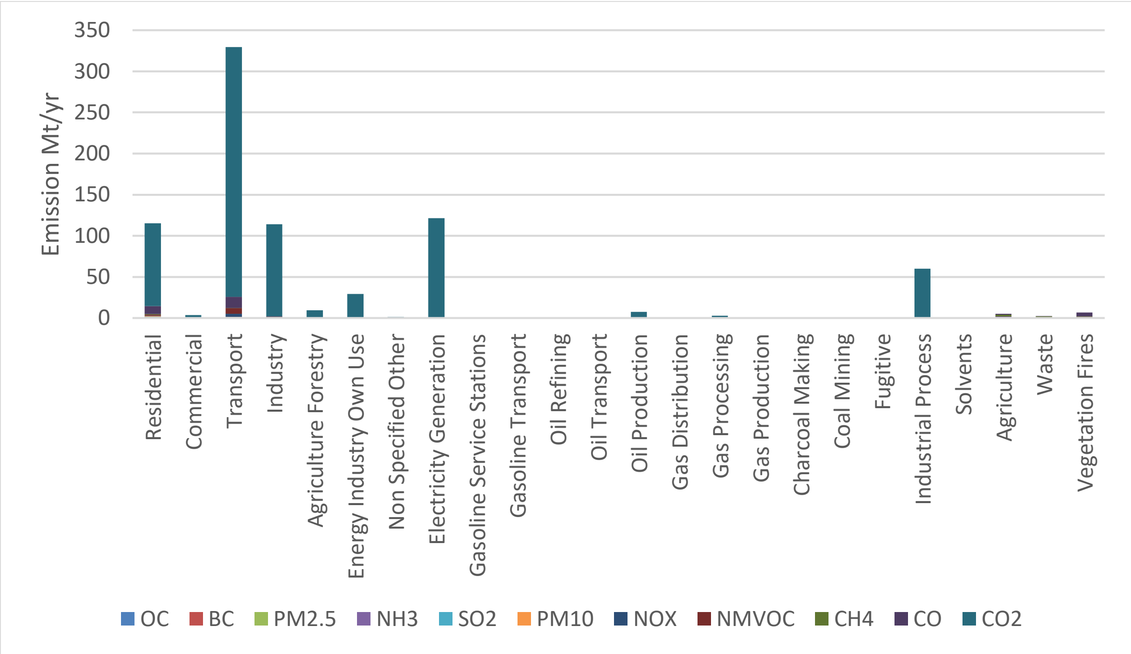

Figure 3-9 Total emissions by pollutant from key sectors for Indonesia in 2010.

The results of the sector-wise anthropogenic emission estimates presented in Table 3-17 shows variations in emissions by sources for different pollutants which will be discussed further in this section.

Table 3-17 Emission estimates for Indonesia in kt/yr including uncertainty bounds (%)

	OC	BC	PM2.5	NH3	SO2	PM10	NOX	NMVOC	CH4	CO	CO2
Demand	489	223	1,222	123	1,176	1,436	4,879	8,122	691	24,387	559,445
Residential	363	106	835	109	102	1,043	280	1,246	631	9,808	100,572
Commercial and Public Services	2	2	5	0	6	5	36	5	3	10	3,589
Transport	84	91	264	11	573	264	4,020	6,715	41	13,833	303,514
Industry	37	19	105	1	373	110	376	149	15	702	112,303
Agriculture Forestry and Fishing	3	5	12	0	20	12	117	6	0	16	9,199
Energy Industry Own Use	0.1	0.0	1	1	84	1	45	1	1	17	29,136
Non Specified Other	0.1	0.2	0.3	0.0	16	0.3	5	0.3	0.0	1	1,132
Transformation	3	1	9	3	522	13	231	484	401	216	130,879
Electricity Generation	0.3	0.3	5	2	401	8	223	3	2	42	120,671
Gasoline Service Stations	-	-	-	-	-	-	-	66	-	-	-
Gasoline Transport and Depots	-	-	-	-	-	-	-	10	-	-	-
Oil Refining	-	-	-	-	121	-	8	205	2	12	-
Oil Transport	-	-	-	-	-	-	-	10	1	-	0
Oil Production	-	-	-	-	-	-	-	111	159	-	7,303
Gas Distribution	-	-	-	-	-	-	-	1	72	-	4
Gas Processing	-	-	-	-	-	-	-	9	10	-	2,838
Gas Production	-	-	-	-	-	-	-	14	131	-	62
Charcoal Making	2	0.3	4	1	-	4	0.3	55	23	163	-
Coal Mining	-	-	-	-	-	-	-	-	1	-	-
Non Energy	321	47	596	1,579	38	763	297	954	4,167	6,101	59,766
Fugitive	-	5	5	-	-	-	-	0.0	0.0	-	-
Industrial Process Emissions	0.0	0.1	34	17	4	128	8	55	-	30	59,766
Solvents	-	-	-	-	-	-	-	346	-	-	-
Agriculture	67	10	112	1,469	6	118	163	118	1,853	1,184	-
Waste	15	2	27	34	1	33	14	63	2,001	106	-
Vegetation Fires	239	30	418	60	26	483	113	372	313	4,780	-
Total	812	271	1,827	1,704	1,736	2,211	5,406	9,561	5,259	30,704	750,091
Lower Bound	23%	25%	20%	32%	33%	20%	40%	60%	30%	40%	5%
Upper Bound	42%	40%	32%	33%	105%	32%	42%	78%	58%	42%	5%

	OC	BC	PM2.5	NH3	SO2	PM10	NOX	NMVOC	CH4	CO	CO2
Demand	489	223	1,222	123	1,176	1,436	4,879	8,122	691	24,387	559,445
Residential	363	106	835	109	102	1,043	280	1,246	631	9,808	100,572
Commercial and Public Services	2	2	5	0	6	5	36	5	3	10	3,589
Transport	84	91	264	11	573	264	4,020	6,715	41	13,833	303,514
Industry	37	19	105	1	373	110	376	149	15	702	112,303
Agriculture Forestry and Fishing	3	5	12	0	20	12	117	6	0	16	9,199
Energy Industry Own Use	0.1	0.0	1	1	84	1	45	1	1	17	29,136
Non Specified Other	0.1	0.2	0.3	0.0	16	0.3	5	0.3	0.0	1	1,132
Transformation	3	1	9	3	522	13	231	484	401	216	130,879
Electricity Generation	0.3	0.3	5	2	401	8	223	3	2	42	120,671
Gasoline Service Stations	-	-	-	-	-	-	-	66	-	-	-
Gasoline Transport and Depots	-	-	-	-	-	-	-	10	-	-	-
Oil Refining	-	-	-	-	121	-	8	205	2	12	-
Oil Transport	-	-	-	-	-	-	-	10	1	-	0
Oil Production	-	-	-	-	-	-	-	111	159	-	7,303
Gas Distribution	-	-	-	-	-	-	-	1	72	-	4
Gas Processing	-	-	-	-	-	-	-	9	10	-	2,838
Gas Production	-	-	-	-	-	-	-	14	131	-	62
Charcoal Making	2	0.3	4	1	-	4	0.3	55	23	163	-
Coal Mining	-	-	-	-	-	-	-	-	1	-	-
Non Energy	321	47	596	1,579	38	763	297	954	4,167	6,101	59,766
Fugitive	-	5	5	-	-	-	-	0.0	0.0	-	-
Industrial Process Emissions	0.0	0.1	34	17	4	128	8	55	-	30	59,766
Solvents	-	-	-	-	-	-	-	346	-	-	-
Agriculture	67	10	112	1,469	6	118	163	118	1,853	1,184	-
Waste	15	2	27	34	1	33	14	63	2,001	106	-
Vegetation Fires	239	30	418	60	26	483	113	372	313	4,780	-
Total	812	271	1,827	1,704	1,736	2,211	5,406	9,561	5,259	30,704	750,091
Lower Bound	-23%	-25%	-20%	-32%	-33%	-20%	-40%	-60%	-30%	-40%	-5%
Upper Bound	+42%	+40%	+32%	+33%	+105%	+32%	+42%	+78%	+58%	+42%	+5%

The emission in each subsector can be seen on which subsector that produce most of emission. For example, in the Industrial Processes subsector, mineral products such as cement and lime production emit the most pollutant. The use of fossil fuel is mainly as coal in power generation and petroleum in the transportation sector. Various policy options can be considered, based on the results of this emission inventory with an emphasis on reducing emissions in transportation, power generation and the residential sector with, for example, a focus on fuel substitution. Substituting fossil and wood fuels with cleaner fuels such the use of natural gas or based on sustainable sources of renewable energy would substantially reduce emission. The greatest uncertainties are coming from SO_2 and NMVOC which attributed the uncertainty in emission factors and activity data.

A cleaner fuel such as liquid petroleum gas (LPG) could replace wood biomass in residential sectors, or coal-fired power stations could be replaced with gas-based power stations in the power generation sector (Purwanto et al., 2016). A cleaner fuel such as compressed natural gas (CNG) might also replace the use of diesel in vehicles. On the other hand, a renewable energy such as biodiesel could replace diesel in the transportation sector, but this would only reduce net emissions if biodiesel development follows sustainable development practices (Khatun et al., 2017).

Biogas could be used to replace wood fuels and a renewable energy source such as geothermal or wind energy could also be used to replace coal-based power stations. To understand the potential of such fuel switches requires the use of scenario building to ensure energy demand is met and estimate the associated emissions from different energy mixes. This will be explored further in Chapter 4.

3.3.2. Air pollution emission estimates

a. SO_2 emissions

The total SO_2 emission estimated for Indonesia in 2010 was 1,735 kt/yr. Transport 573 kt/yr (33%) and electricity generation 400 kt/yr (23%) were the largest source sectors of SO_2 as shown in Figure 3-10. Energy related sector contributed the most SO_2 pollutant by 98%.

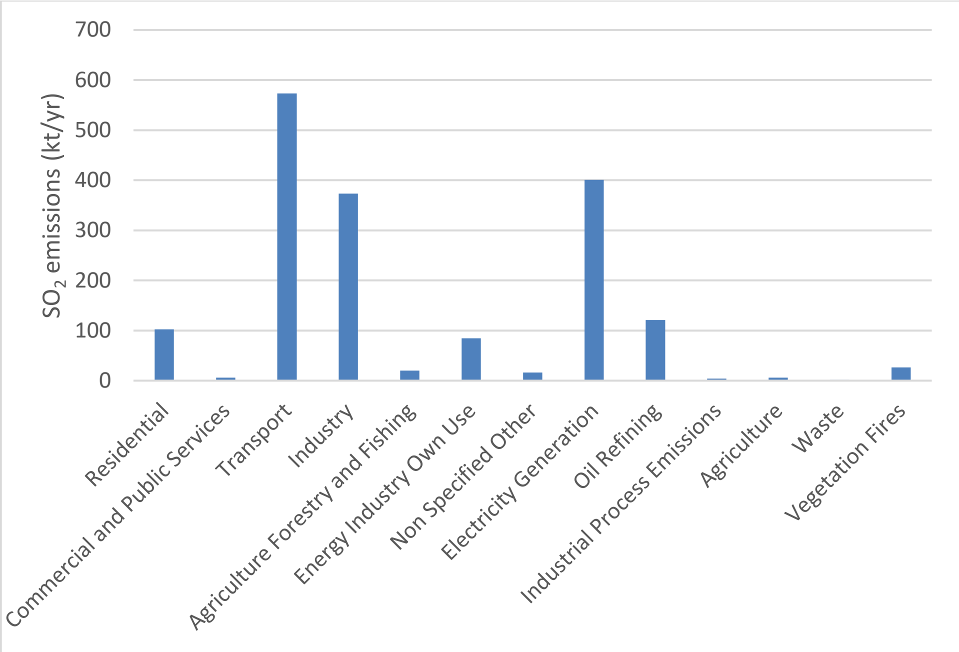

Figure 3-10 SO_2 emissions in kt/yr estimated by source sector for Indonesia in 2010.

b. NOx emissions

Total emissions of NO_x in Indonesia in 2010 were 5,406 kt/yr. Figure 3-11 shows that NO_x emissions were dominated by the road transport sector which accounted for 4,019 kt/yr (74%) of total emissions. In the road transport sector heavy duty vehicles and buses contribute 90% of total emission in road transport sector. NOx emission followed by lesser contributions from the industry combustion sector at 376 kt/yr (7%) of NO_x. The lower bound of NO_x emission is 40% and the upper bound is 42%. Energy related sector contributed the most NO_x pollutant by 95%.

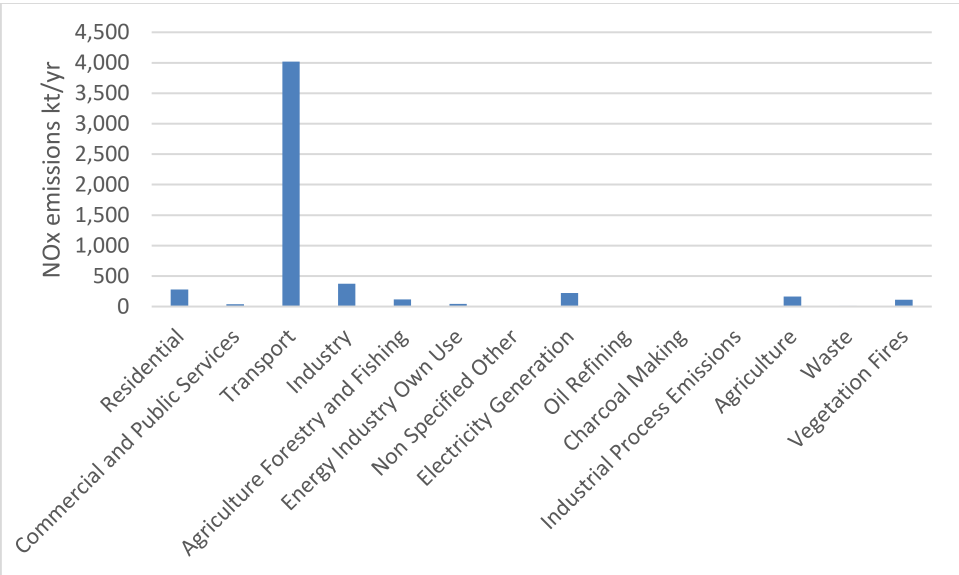

Figure 3-11 NO_x emissions in kt/yr estimated by emission sector for Indonesia in 2010 *c. CO emissions*

In 2010, total CO emissions in Indonesia were 30,704 kt/yr. CO emissions were mainly from road transport (45%), residential (32%) and vegetation fires (16%) as shown in Figure 3-12. The lower bound of CO emission is 40% and the upper bound is 42%. Energy related sector contributed CO pollutant by 80%.

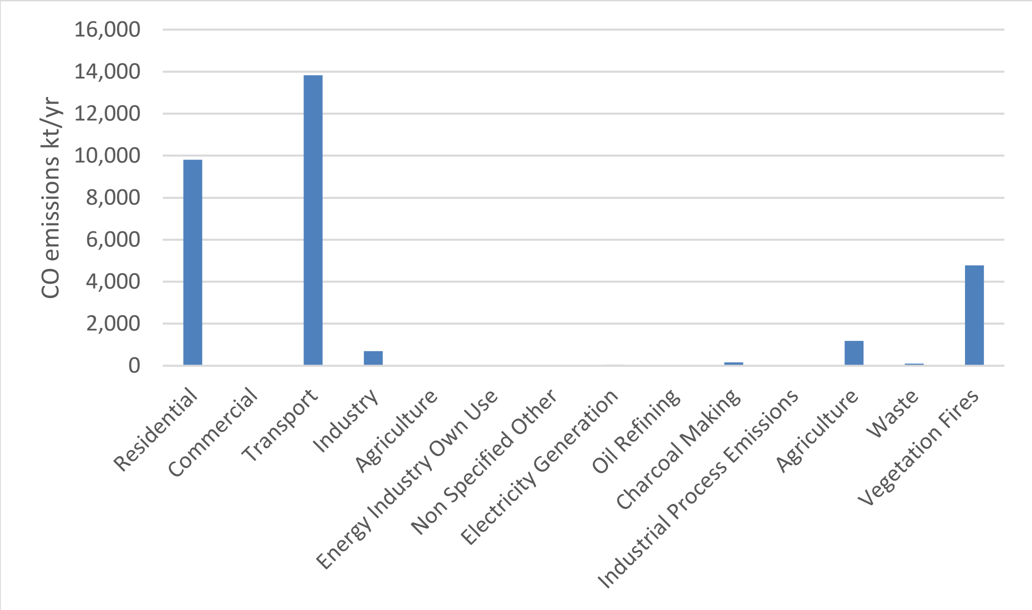

Figure 3-12 CO emissions in kt/yr estimated by emission sector for Indonesia in 2010

d. NMVOC emissions

NMVOC emissions were mainly from road transport which contributed 6,715 kt/yr (70%) followed by the residential sector at 1,245 kt/yr (13%) of total NMVOC emissions as shown in Figure 3-13. The lower bound of NMVOC emission is 60% and the upper bound is 78%. Energy related sector contributed NMVOC pollutant by 90%.

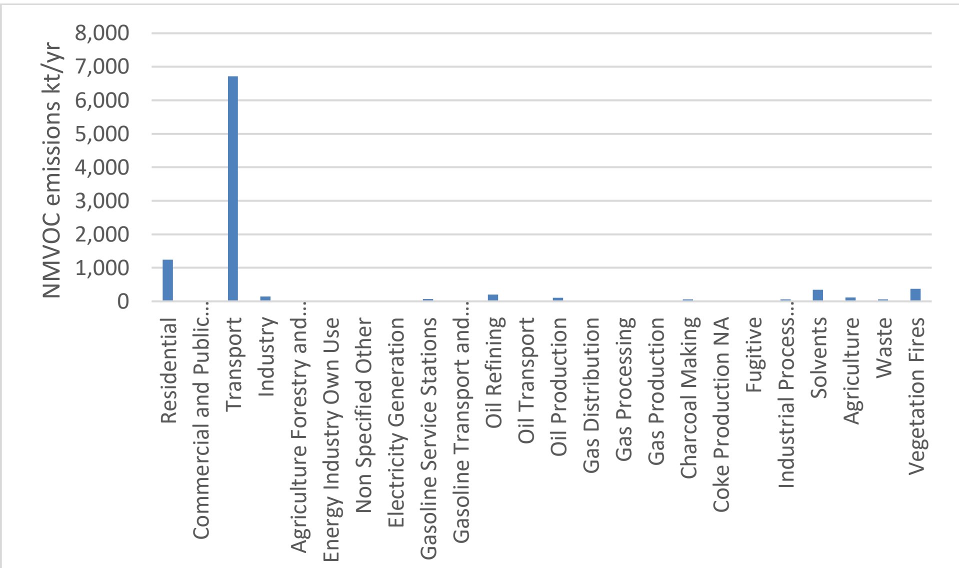

Figure 3-13 NMVOC emissions in kt/yr estimated by emission sector for Indonesia in 2010

e. NH_3 emissions

NH_3 emissions (Figure 3-14) were mainly from agriculture which contributed 1,468 kt/yr (86%). The lower bound of NH_3 emission is 32% and the upper bound is 33%. Energy related sector contributed NH_3 pollutant by 7%. Livestock enteric fermentation and manure management contribute the most NH_3 emission in agriculture sector.

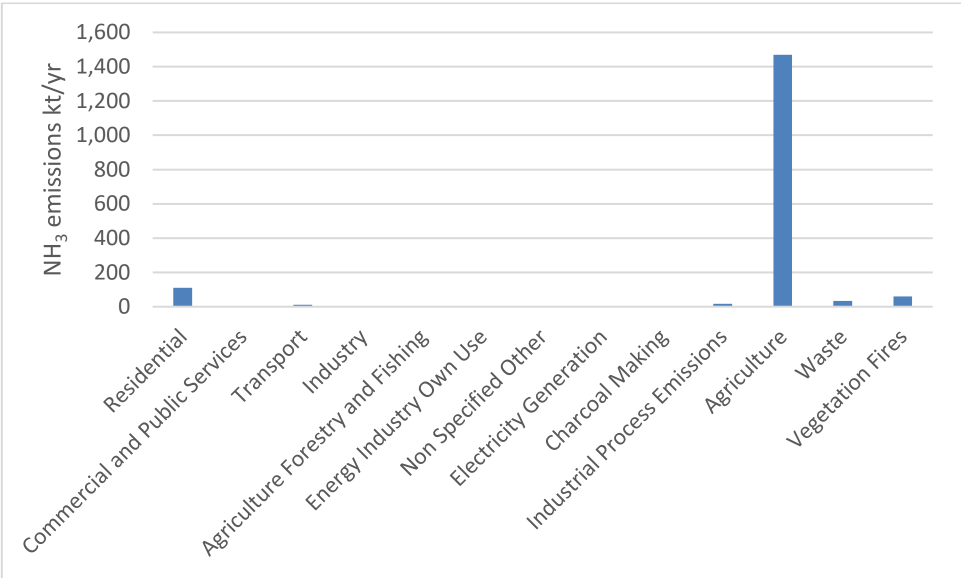

Figure 3-14 NH_3 emissions in kt/yr estimated by emission sector for Indonesia in 2010

f. BC emissions

BC emissions were mainly from the residential sector (contributing 39% of total BC emissions), followed by road transport (at 34%) and vegetation fires (at 11%) as described in Figure 3-15. The lower bound of BC emission is 25% and the upper bound is 40%. Energy related sector contributed BC pollutant by 82%. In road transport diesel vehicle such as heavy duties vehicle and buses contribute the most BC emission. In residential sector traditional stove wood contribute the most BC emission by burning wood.

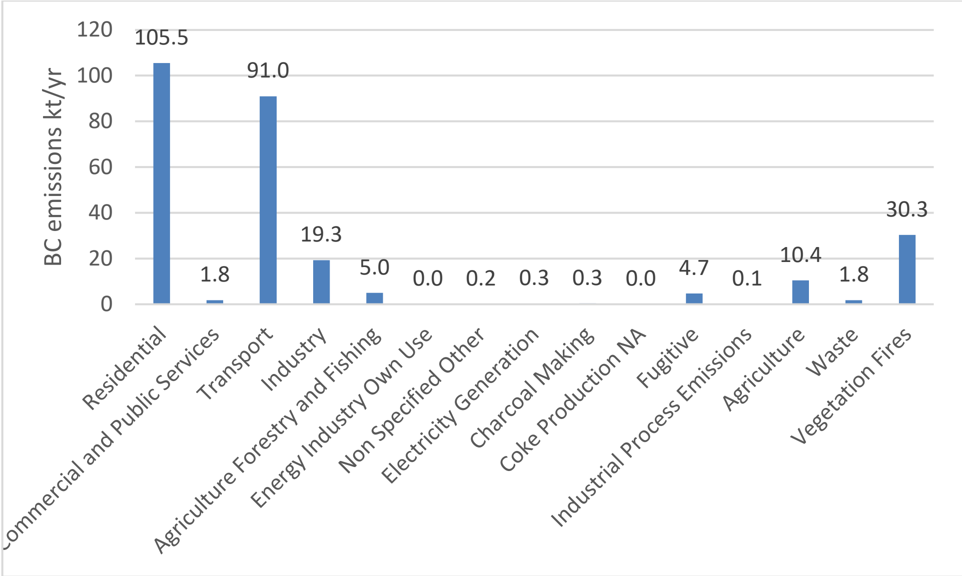

Figure 3-15 BC emissions in kt/yr estimated by emission sector for Indonesia in 2010

g. OC emissions

OC emissions (Figure 3-16) were mainly from residential sector at 362 kt/yr (comprising 45% of total OC emissions), followed by the vegetation fires at 239 kt/yr (29%) and transport at 83 kt/yr (10%). The lower bound of OC emission is 23% and the upper bound is 42%. Energy related sector contributed OC pollutant by 60%. The main emission in residential sector coming from traditional stove wood.

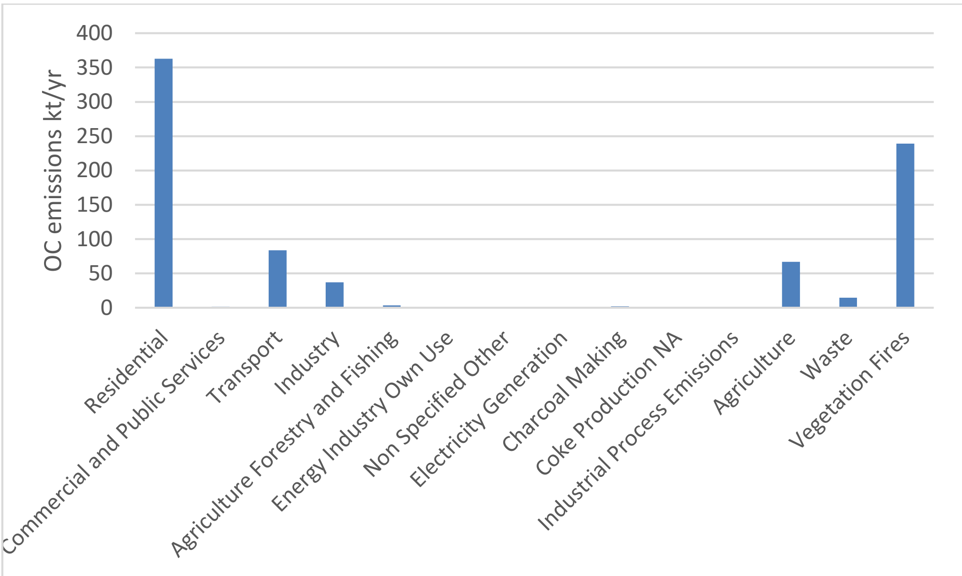

Figure 3-16 OC emissions in kt/yr estimated by emission sector for Indonesia in 2010

h. $PM_{2.5}$ emissions

Figure 3-17 shows that $PM_{2.5}$ emissions, other than BC or OC, predominantly came from residential sector at 835 kt/yr (comprising 46%of total $PM_{2.5}$ emissions) followed by the vegetation fires 418 kt/yr (23%) and road transport 263 kt/yr (14%). The lower bound of $PM_{2.5}$

emission is 20% and the upper bound is 32%. Energy related sector contributed $PM_{2.5}$ pollutant by 67%. In the residential sector the use of traditional stove wood contributes the most $PM_{2.5}$ emission.

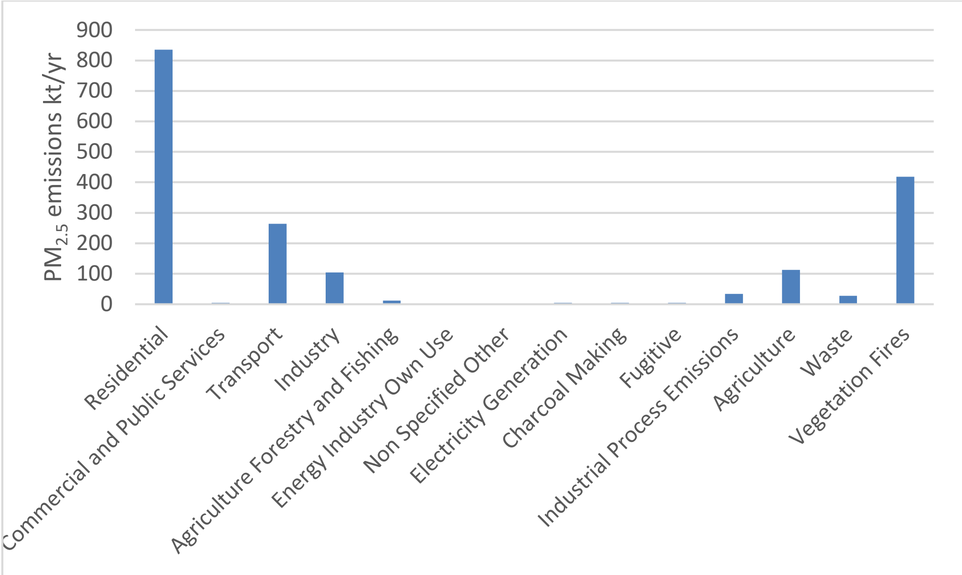

Figure 3-17 $PM_{2.5}$ emissions in kt/yr estimated by emission sector for Indonesia in 2010

3.3.3. GHG emission estimates

a. CO_2 emissions

In 2010, the CO_2 emissions (Figure 3-18) were mainly from combustion in the transport sector at 303 Mt/yr (40%), followed by fuel combustion in the electricity generation sector at 120 Mt/yr (16%), and fuel combustion in industry at 112 Mt/yr (15%). The lower bound of CO_2 emission is 5% and the upper bound is 5%. Energy related sector contributed the most CO_2 pollutant by 92%.

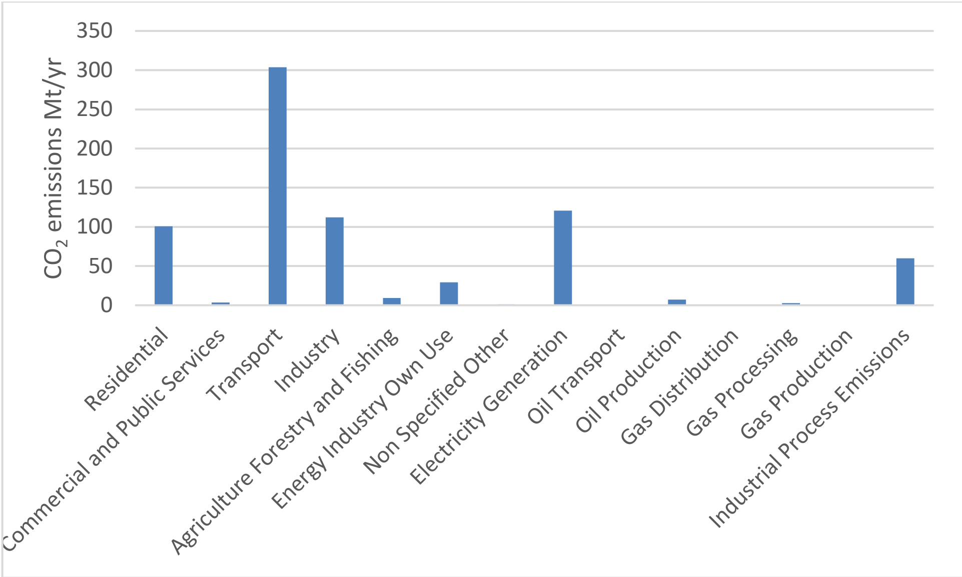

Figure 3-18 CO_2 emissions in kt/yr estimated by emission sector for Indonesia in 2010

b. CH_4 emissions

Figure 3-19 shows that the CH_4 emissions for Indonesia in 2010 were mainly from the waste and agriculture sectors. Waste was the largest source of CH_4 emissions at 2,001 kt/yr (38% of total CH_4 emissions). Methane emissions in the agriculture at 1,853 kt/yr (35%). The residential sector was the next largest source emitting 631 kt/yr (12%) of CH_4. The lower bound of CH4 emission is 30% and the upper bound is 58%. Energy related sector contributed CH_4 pollutant by 21%. Within energy sector, oil and gas production contribute the most CH_4 emission by 72% of total emission.

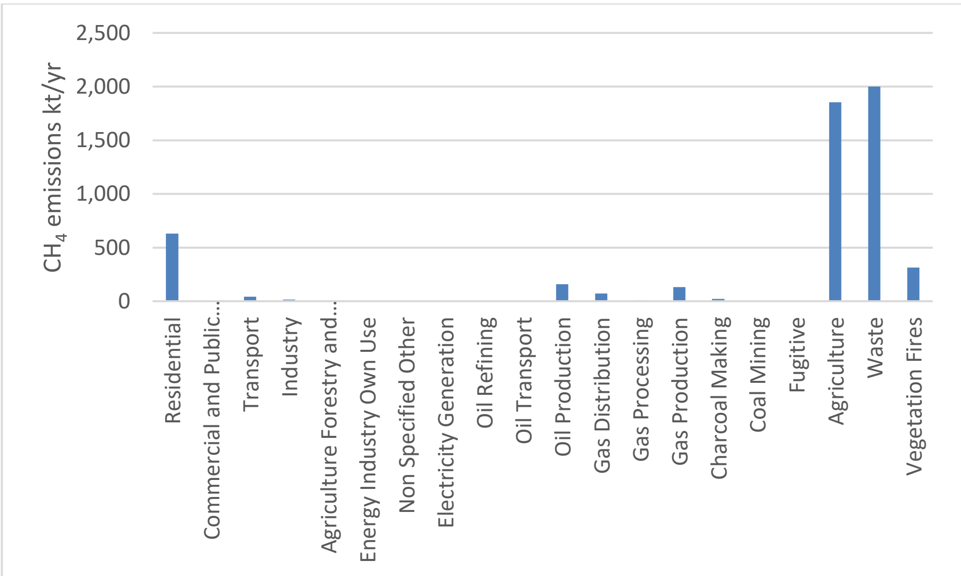

Figure 3-19 CH_4 emissions in kt/yr estimated by emission sector for Indonesia in 2010

3.4. Comparison of emission results with other inventories

A comparison with other published emission inventories such as EDGAR 2008, GAINS 2005 and Permadi (2010) is shown in Table 3-18.

Table 3-18 Comparison of emissions by pollutants for Indonesia for current year estimates.

Species	2010 (This Study)	EDGAR (2008)	GAINS (2010)	REAS (2008)	Permadi (2010)
SO_2	1,736	2,433	1,663	1,808	1,014
NO_x	5,406	2,162	1,914	2,817	3,323
CO	30,704	32,246	23,744	22,499	24,849
NMVOC	9,561	4,527	4,557	7,316	4,077
NH_3	1,704	1,617	1,384	1,743	1,276
PM_{10}	2,211	3,454	1,897	1,327	2,154
$PM_{2.5}$	1,827	2,023	1,559	997	1,728
BC	271	173	289	179	246
OC	812	711	593	682	718
CH_4	5,259	10,300	8,659	11,398	3,979
CO_2	750,091	396,353	-	573,207	540,275

Results for all pollutants apart from NMVOC and NOx in this study are within the range of other published inventories as shown in Figure 3-20.

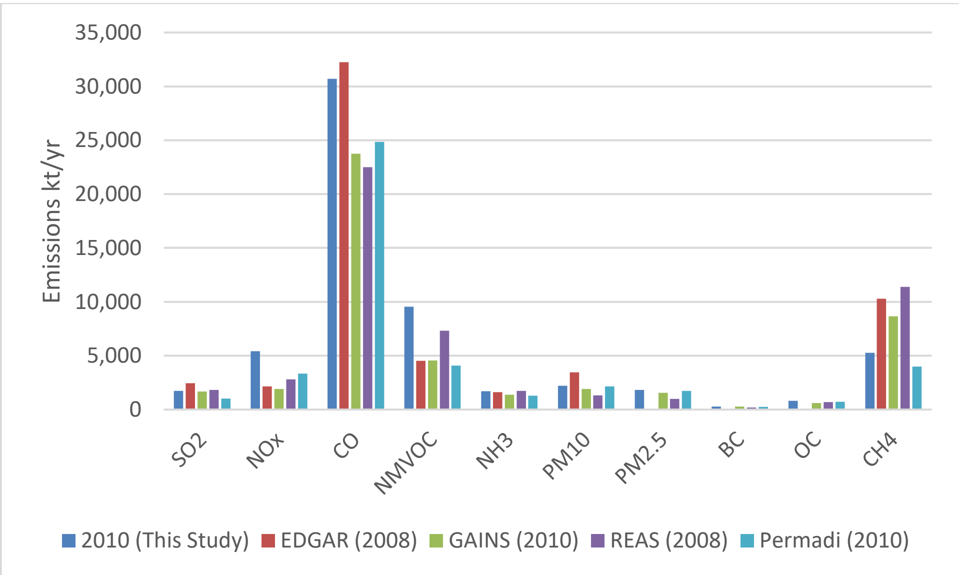

Figure 3-20 Comparison of emission by pollutants for Indonesia

However, the difference between each emission inventory can be seen in each specific pollutant such as in CH_4. The explanation of this differences as follows. The amount of CH_4 in this study is 5,258 kt/yr which is higher than Permadi 3,979 kt/yr. The explanation of this is that Permadi did not cover area such as rice paddy (931 kt), wastewater handling (883 kt) and traditional brick/tile kiln production. However, the amount of CH_4 compared with EDGAR/REAS/GAINS is much lower. The explanation of this is due to the different estimation on the emissions from enteric fermentation, rice cultivation and waste emissions within the EDGAR inventory as shown in Table 3-19.

Table 3-19 Comparison of CH_4 kt/year with EDGAR and GAINS

Area	EDGAR	GAINS	This Study
Enteric fermentation	1,080	-	751
Rice cultivation	2,750	2,725*	1,048
Waste	2,596	1,386	2,001

Note: *) GAINS data is for total agriculture data, not rice cultivation only

3.5. Conclusion

In this chapter, an emission inventory for Indonesia has been developed following standardised methods described in the GAP Forum emission inventory manual (Vallack and Rypdal 2019). This inventory has then been analysed to compare it with other inventories that describe emissions for Indonesia and to identify which sectors should be prioritized for emission reduction. The activity data used in this Indonesian emission inventory are mainly taken from the Government of Indonesia data sources. The primary data for brick kilns are from the field survey. This analysis indicates that a fuel substitution policy focussing on prioritized sectors such as transportation, power generation and residential sectors would be worth investigating as part of an energy transition. Further scenario analysis, based on the emission inventory, is required to understand the long-term emissions and their impacts and this will be described in Chapter 4 Emission scenario.

In the scenario analysis approach, several energy scenarios related to the prioritized sectors will be investigated. A mitigation policy such as fuel substitution need to be analysed to understand its performance in the long term. A transition to using cleaner sources of energy or transition into sustainable renewable energy will show a significant decrease in air emissions. These considerations will form the basis of mitigation scenario development and analysis carried out in the next Chapter 4 Emission scenario

Notes:

Chapter 4 Emission scenario development

4.1. Introduction

The chapter looks to explore important aspects in Indonesia energy transition through stakeholder interview coupled with an assessment of the feasibility of energy supply given the countries geography. The emission scenario development is required to improve the current Indonesia government energy transition. The current Indonesia government energy transition is not feasible for the reasons of rate of energy transition and the complex geography of Indonesia. This chapter describes the development of a number of energy scenarios for Indonesia for a 20 year period between 2010 and 2030.

These scenarios are based on existing energy scenarios that have been developed by the Indonesia government to define an energy transition that can be sustainable from an environmental, social and economic viewpoint (UKP4, 2014). This study has modified these government scenarios according to expert opinion from a variety of energy stakeholders (from government, business, research and development) describing what level of energy transition they believe is likely over the coming decades. The scenarios were also modified through analysis of the feasibility of different energy mixes as determined by the quantity of energy that can be supplied according to geographical constraints that are unique to Indonesia.

The chapter describes the methods used to develop energy transition scenarios based on expert opinion, feasibility and drivers of change that can identify energy mixes that will ensure energy supply meets demand in a sustainable manner from environmental, economic, social and political viewpoints. The chapter briefly describes the energy transitions planned for Indonesia and how these are intended to change the energy mix for a variety of outcomes, this description includes an assessment of whether these transitions are likely to be feasible. This follows on from the more generic discussion on energy transition described in Chapter 2. The chapter then describes the development of scenarios that specifically target a low emission development pathway using the LEAP-IBC tool and the knowledge that this requires in the drivers of supply and demand such as population, GDP, technology as well as the feasibility, cost, and geographical constraints. The methods used to describe three scenarios are provided Baseline, Modified government scenario (GOVT) and maximum feasible reduction scenario (MFRE). The baseline scenario is representing a continuation of current historical trend. MFRE scenario is a maximum feasible reduction scenario that describes a future in which use of Indonesia's potential renewable energy resources is maximised. The modified Indonesian government scenarios reflect a more realistic view of the likely future energy supply mix. These scenarios are then applied to show how emissions associated with energy use will change over the period from 2010 to 2030.

4.2. Energy scenarios

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (Nakicenovic et al., 2000). Scenarios can describe a demographic, social, economic, technological, environmental, and policy future for a particular region or country and will tend to focus on a particular aspect of development for example energy transition (Jefferson, 2008) or low emission development (Smits, 2015). Scenarios tend to be formulated using a methodology that identifies driving forces and key uncertainties such as economic, politics and new technology.

The purpose of scenarios is to develop a narrative description of the future with the intention to gain insight into the consequences of such a narrative for some aspect of development. The description of the future is often provided by expert opinion, for example, setting out the likely changes in the future Indonesia energy system (Kennedy, 2018). The terms ‘scenario’ or ‘storyline’ are often used interchangeably. In this thesis the definition of scenarios and storylines refers to that used by the IPCC (Nakicenovic et al., 2000). A storyline is defined as a narrative description of a scenario, highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces. By contrast, scenarios are defined as projections of a potential future based on a quantified storyline (Nakicenovic et al., 2000).

An energy transition scenario is any scenario that describes the future state of energy systems from the perspective of a fuel switch, such as a change from a certain type of energy supply mode into another type of energy supply mode in the future (Markard et al., 2012). As described in Chapter 2 energy transitions will have environmental, economic, social and political consequences and therefore the rationale for encouraging energy transitions can be for a variety of reasons e.g. to prevent environmental degradation by moving to low emission energy systems or enhancing energy security by switching to more accessible energy supply modes.

This thesis focusses on the role that energy transition can play in low emission development strategies especially in PM and GHGs reduction. The importance of such energy transitions is evident when considering that globally, energy production and consumption are the major sources of both air pollutants and GHGs accounting for 85% of sum of total pollutants of particulate matter, sulphur oxide and nitrogen oxide emissions, and accounting for 40% of CO_2 emissions (IEA, 2016). In the IEA’s global country ranking of CO_2 emissions from fuel combustion, Indonesia was ranked 13th accounting for 442 million tonnes in 2015 (IEA, 2016). Because of concerns such as these, Indonesia is engaging in a more environmentally sustainable, lower-emission energy transition with plans to increase the use of renewable energy and clean fuels (UKP4, 2014, p.4). However, sources of GHGs (which are the focus of the Indonesian government energy transition plans) are often the same as those for air pollutants. This provides an important opportunity to coordinate actions on both GHGs and air pollutants in order to maximise benefits. This approach aims to overcome the problems of policy development often occuring in ‘silos’, where climate decision-makers pay little attention to air quality issues, and vice-versa.

This thesis therefore adopts a low emissions development (LED) approach to explore alternative scenarios for Indonesia’s energy transition in which both air pollutant and GHG emissions are considered in an integrated manner. This LED approach aims to define a forward looking national economic development plan or strategy that encompasses low-emission and or climate-resilient growth (Clapp et al., 2010). In Indonesia, various LED programmes have led to the development of the existing national plan to reduce emissions by at least 26% below business-as-usual levels by 2020 (Hasan et al., 2012). Indonesia's National Action Plan for Greenhouse Gas Reduction sets forth a wide range of mitigation activities and emission-reduction targets across major sectors (USAID, 2010).

LED programmes in Indonesia aim to integrate mitigation and adaptation into the Indonesian Medium-term Development Action Plan and Long-term Development Action Plan 2005-2025 (MOEF, 2010) and synergies can be achieved by considering emissions of both air pollution and GHGs and their impact together and this integrated approach will be applied in the analysis in this thesis. This thesis focus on enhancing analysis of these existing policies.

The Indonesia government, and specifically the Ministry of Energy and Mineral Resources (MOEMR), has also developed its own scenarios focusing on the Indonesian energy system. In Indonesia, energy scenarios could include consideration of the feasibility of changes in energy mix (i.e. dependent upon the characteristics of energy supply and demand and the influence of geography) as well as the influence on various factors such as social, economic and political factors. For example, energy demand in Indonesia is characterised by high consumption of traditional solid biomass for cooking (Mahlia et al., 2001). Geographical factors include the large number of islands and variability in the availability of different energy sources across these islands and island groups. Socio-political factors might include the degree of alignment with current legislation the political aim of the energy transition (e.g. energy access, low emission development). In Indonesia, a specific target such as a renewable energy target or a specific development target such as electrification ratio has been used in several regulations in the past.

The objective of this chapter is to develop a set of energy scenarios for Indonesia for LED. These scenarios build on existing government scenarios but also consider what energy mix is feasible in different locations given Indonesia's geography.

4.3. Indonesia's energy transition

As of 2010, Indonesia has Total Primary Energy Supply (TPES) of 210 Million Tonnes of Oil Equivalent (Mtoe) and expected to have 400 Mtoe by 2030 (MOEMR, 2017). Over recent decades, the Indonesian government has been developing energy transition scenarios towards clean and sustainable energy systems. In developing energy scenario, Indonesia government use energy usage share as capacity target. The capacity target is currently used by Indonesia government to understand the proportion of renewable energy share in the country (ESDM, 2017). The capacity target is therefore an important indicator in the development of energy scenarios.

There are several energy and emission scenarios that have been developed, which are described in Table 4-1. The renewable and clean energy scenario based on the National Energy Policy (NEP) under government regulation 'no. 70 year 2014'. This scenario aims to have 25% of total energy from renewable sources and 23% from natural gas by 2025 as the capacity target. The Indonesia government, specifically the Ministry of Energy, has also developed a GHG scenario which aims to have a 29% emission reduction, and specifically an 11% emission reduction in energy sectors by 2030. This GHG scenario was developed as Indonesia's contribution to the UNFCCC 2nd National Communication 2011.

As such, each of these scenarios have been developed built for different purposes. For example the National Gas Roadmap 2014-2030 scenario only focusing on increase the production of gas energy.

Table 4-1 Various Indonesian government scenario

Energy Scenario	Key Feature	Policy	Timeline
Renewable and clean energy scenario	Increase the use of renewable energy. Reduce the use of fossil fuel	National Energy Policy 2025-2050 (KEN – Kebijakan Energi Nasional), based on Government Regulation no 79/2014	2025-2050
National gas roadmap scenario	Aim to increase the share of gas to 30% by 2025	National Gas Roadmap 2014-2030	2014-2030
Greenhouse gas reduction scenario	Reduce greenhouse gas. Reduce the use of fossil fuel	National Action Plan for Reducing Greenhouse Gas Emissions (RAN GRK - Rencana Aksi Nasional Gas Rumah Kaca), based on Pres. Decree 61/2011	2011-2030
Energy conservation scenario	Energy conservation. Reduce the use of energy	National Energy Conservation Plan (RIKEN - Rencana Induk Konservasi	2009-2030

		Energi Nasional), based on Government Regulation no 70/2009	
Electrification scenario	Increase electrification ratio	National Electricity Plan (RUKN - Rencana Umum Ketenagalistrikan Nasional), based on Ministry Decree no 2682K/21/MEM/2008 Tahun 2008 and PLN Electricity Business Plan (RUPTL - Rencana Usaha Penyediaan Tenaga Listrik) 2015-2024, based on Ministry Decree no 0074 K/21/MEM/2015	2009-2030

Based on the Indonesian government scenarios that available (see Table 4-3), there are four scenarios that have been developed by the Indonesian government to envision future energy system up to 2030. However, we focus on the two main energy scenarios. The first scenario, the 'renewable and clean energy' scenario, assumes that the use of renewable energy will be increased from 8% share in 2010 to a 21% share in 2030. The second scenario, the 'national gas roadmap' scenario, assumes that natural gas will be increased from 18% to 33% share in 2030, while other sources of energy will be decreased. Both of these scenarios have become the focus of government planning in Indonesia (MOEMR, 2017)

The selection of these two particular scenarios is made as they focus on energy development. The first scenario (Planned government renewable energy scenario - RENGOV) assumes that renewable energy will be dominating the energy mix with the development of renewable energy power plants and domination of renewable sourced fuels in the transportation sector. The second scenario (Planned government clean energy scenario - CLEANGOV) assumes that natural gas will be dominating the energy mix mainly assuming that there are new reserve discoveries for natural gas in Indonesia.

There are two main challenges with the Indonesian government scenarios RENGOV and CLEANGOV. Firstly, they both use unrealistic capacity targets set by the Indonesian government that do not reflect the current socio-political economy situation (Mujiyanto and Tiess, 2013). For example, as of 2017 the renewable energy share in Indonesia is still at less than 7% which is behind the target of 12% as of 2017 (ESDM, 2017). There also exist plans for the development of new coal or gas fired power plants which contradict the renewable energy scenario (Merdeka, 2019). The delay in the development of new renewable energy power plants scheduled in 2019 to 2024 also contributes to unrealistic targets to achieve renewable energy (Merdeka, 2019). As such, the RENGOV scenario targets do not reflect the current situation in Indonesia and are likely to be overly optimistic.

Secondly, various studies indicate that the use of renewable energy instead of fossil fuel will decrease GHGs and air pollution (Haryanto and Franklin, 2011). However, in Indonesia the connection between GHGs, air pollution and energy has not been explored. For example, In the government energy scenarios, air pollutant emission reduction is not prioritized (Santoso et al., 2011) and where it is included, it is considered separate from GHG emissions. Further, energy generation does not take account of the social and health costs of its air pollution (Vitalstrategies, 2018).

In this thesis, we focus on a capacity target for renewable energy and establish this target on consideration of the geography of Indonesia. The term 'capacity target' means the specific percentage of renewable to non-renewable energy that should be achieved in the future (MOEMR, 2017).

In this thesis, developing energy transition scenarios for Indonesia, there are a number of important factors that should be considered which include: i. Infrastructure; ii. Geography; iii. Accessibility and iv. Sustainability. 1) Transition to clean and renewable energy; 2) Indonesia as single island with integrated grid; 3) Exclusion of traditional solid biomass energy; 4) Focus on increasing electrification ratio; 5) Focus on increased energy consumption and energy access.

4.3.1. Infrastructure

Energy infrastructure is defined as large scale technology that enables the transport or flow from energy production to consumption (Farrell et al., 2004). Energy infrastructure includes oil and gas production (such as oil refinery), transportation, refinery and storage (such as batteries or backup generators). Energy infrastructure is crucial in the development of sustainable energy systems. For example, advanced technology and infrastructure for energy would make use of efficient transportation thus significantly reducing the primary energy requirement, as well as emissions of pollutants associated with energy provision (Das and Ahlgren, 2010).

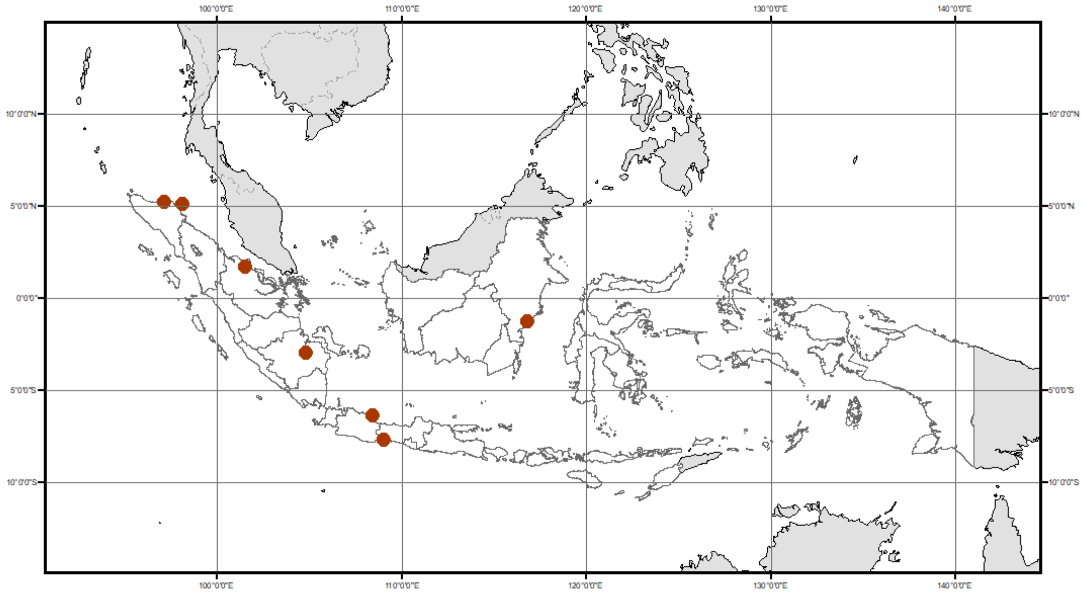

Figure 4-1 Map of oil refinery showed in red dot

Currently, Indonesia has 10 oil refineries of which 5 are located on Java Island accounting for 51% of total national refineries capacity. Natural gas distribution in Indonesia is uniquely problematic due to geographical factors where most of the islands are not connected to the gas pipeline network. Transportation of gas is usually in the form of liquefied natural gas (LNG) for export. Oil and gas energy infrastructure development in Indonesia is slow and capacity is weak (Boyd et al., 2010). Further, infrastructure development should be prioritized between export-oriented versus domestic use of oil and gas.

The transition to renewable energy is challenging due to the fact that most of the energy infrastructure in Indonesia is currently built around the supply and use of fossil fuel based energy such as oil and gas (Rachmatullah et al., 2007). For example, in the electricity generation sector, the electric grid is not designed to have a load balancer that can be used for co-generation with intermittent renewable energy such as wind energy. In transportation sectors, all the gas stations are built for a petroleum and do not have electricity charging systems to support electric vehicle use.

In terms of energy distribution infrastructure, oil distribution is mainly owned by state own enterprise (SOE), in this case, Pertamina. Oil and gas production infrastructure is dominated by foreign companies using production sharing contract (PSC) agreements. This production infrastructure is usually built on a large-scale development such as deep-water exploration or natural gas liquefaction that requires large capital. Adoption of technology in oil production is usually slow and most of the technology is not owned by Indonesia, a good example of this is in oil exploration or gas liquefaction (Soentono and Aziz, 2008).

Therefore, these state-owned enterprises and government ministries are key stakeholders in Indonesian energy systems. State-owned enterprises such as Pertamina for oil and gas and PLN for electricity are major energy suppliers in Indonesia. PLN has control over 70% of the electricity generation and most of the transmission line and is the biggest coal consumer in Indonesia. In the coal sector, state-owned enterprises such as PT Tambang Batubara, PT Bukit Asam Tbk, and PT Aneka Tambang Tbk are major players in the coal production. In plantation sectors including wood, palm oil and rubber companies such as PT Perkebunan Nusantara and Perum Kehutanan Negara are major players owned by the government.

The energy regulator in Indonesia is the Ministry of Energy and Mineral Resources (MEMR), and various government bodies have been established to supervise and manage energy production and distribution such as the National Energy Council (DEN) for developing energy policy, the Indonesia Oil Palm Estate Fund (BPDP) to manage palm oil industry sectors, the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas) to manage contracts and cooperation in the upstream oil and gas business in Indonesia.

Electricity grid

Energy- or electrical-grids are the network used for delivering electricity from the energy production site to end-user consumers (Kaplan, 2009). The electrical grid usually consists of transmission lines and distribution lines. Transmission lines are used to connect energy production sites to other areas, usually involving high voltages of more than 70KV. Distribution lines used to connect individual customers are usually less than 70 KV. In Indonesia, there are three types of transmission line: 275 KV, 150KV, and 70 KV. Distribution lines are usually around 4KV to 13KV for the industrial customer and 220V for the residential customer. The location of Indonesia's electrical grid is shown in Figure 4-2. Due to archipelago geography of Indonesia, connecting all Indonesia to the grid is extremely difficult (Widiyanto et al., 2003). The underwater electricity cable at this moment is not available in Indonesia (DEN, 2019).

Most energy scenario studies assume that Indonesia is one system with one grid connection among the islands but this is a far too simplistic a representation (Hasan et al., 2012; Rachmatullah et al., 2007). For example, studies indicated that the electricity grid that delivers electricity from producers to consumers for all 17,000 islands in Indonesia can either be regarded as being based on the integration of 15 regional grids (Gulagi et al., 2017) or based on an integration of 6 regional grids (Yusuf et al., 2014). Also, the electricity grid networks in Indonesia have widely varying degrees of quality and availability (Karki et al., 2005). This impacting the quality delivery of electricity across the country.

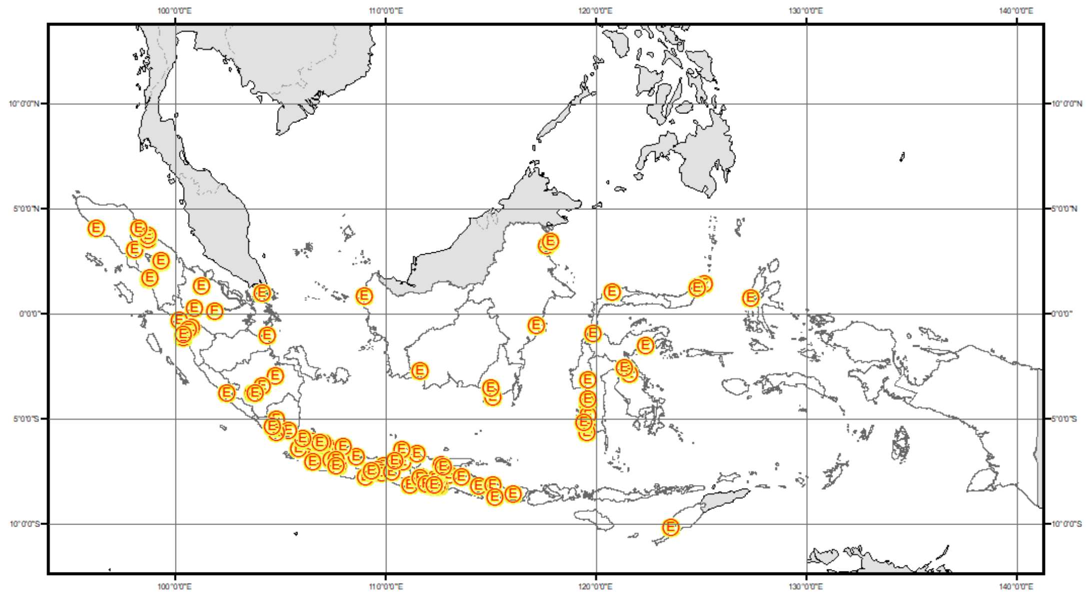

Figure 4-2 Map of the electricity grid (DEN, 2019)

Understanding electrical grid complexity is important as it is determined by the transmission and distribution line length, electricity capacity and electrification ratio, all factors which vary with the complex geographical features of energy resources across Indonesia. Understanding this complexity requires analysis from the perspective of energy geographies (also called territoriality analysis) (Ref).

Two key factors that would improve energy infrastructure in Indonesia are transmission line and length and the distribution line. Transmission lines is the connection between power plant to another plant usually in high voltage, while distribution line is the connection between power plant to the customer usually in low voltage. Improved transmission lines mean that the load can be distributed from one area to another area reducing power outages and resulting in electrical grid coverage for all regions allowing off-grid power to be reduced. This would substantially increase the efficiency of electricity delivery in Indonesia. Transmission length determines how effective a country is in managing its electricity distribution. Ideally, all the transmission lines would cover all areas of Indonesia. For example, the transmission line in Java island should connect all cities that consume most of the energy. This transmission line also should connect all the power plant in Java island, so it could be distributed in all area or could be balancing the peak demand. (Refs for this section)

In Indonesia, the transmission line is called SUTET (Saluran Udara Tegangan Tinggi) and is owned by a state-owned company. Managing the transmission line has high risks with construction of the high voltage transmission lines being expensive and also affects the lives of people living under the line..

Distribution line management might seem not as complex as that for transmission lines. Distribution lines usually follow the road and connect to end-user consumer. To manage the distribution line in the heavily dense area is difficult and there is a huge risk of fire and electricity theft.

Electricity capacity is also important. Each region has a different power plant capacity. There is a gap between the area that has huge capacity and there is an area that has small capacity but has a huge demand. Therefore, managing a balance between limited power generation capacity with the huge demand only could be solved with the effective grid. For example in areas where it is located in the high altitude with mountainous region is it difficult to make a distributed line while there are other places that are located at low altitudes that are easier to make a distributed line.

The recent higher demands for electricity in Indonesia have resulted in a new power plants being developed in those areas that require enhanced supplies of electricit,y for example Sumatra island. On average, Indonesia's national electricity demand is increased by around 9% every year. The transmission network grew by 3.2% per annum, the distribution network by 1.7% per annum, and new generation capacity by 1.4% per annum (ADB, 2016)

Finally, the electrification ratio is also important in terms of energy infrastructure. The electrification ratio is defined as the population that has access to electricity. Electrification is an important indicator that is used by the government of Indonesia to describe their achievement in electricity development. Many development agendas use electrification ratios as an indicator. National energy plans also aim for a higher level of electrification ratio. The electrification ratio is closely related to grid complexity. A higher electrification ratio usually means a higher transmission line and distribution line length. In Indonesia, the electrification ratio is still quite low with the Indonesian government having plans to increase the ratio in the future.

In the future, Indonesia should develop a better electric grid design. The national energy plan intends to have a smart grid implemented in the future to ensure that the load distribution is effectively balanced and energy distribution is improved across Indonesia. Underwater transmission lines are also planned to be implemented making it easier to connect between islands that currently lack electricity supply. These underwater transmission will use High Voltage Direct Current/HVDC, to ensure that islands can be supplied with better electricity quality.(Refs)

One of the plans to developed underwater transmission lines is connecting Sumatra and Java island. By connecting Java and Sumatra island under one grid, the reserve margin or the amount of available capacity divided by demand will reach more than 40%. As of 2018, the reserve margin for Java island was less than 13% (OBG, 2018). Further, better electrical grids also ensures that non-marketable coal power plants can be connected. Non-marketable, in this case, means that the cost of transporting coal to other areas is more expensive than when used directly on the power plant site. The idea of this concept is that coal mining should be close to the distribution network. Therefore, the coal mines that are currently far from distribution networks can be developed as a power plants. This will have many benefits at the same time such as helping to utilize non-marketable coal and would be able to supply with the lowest cost.

4.3.2. Biomass

Transition to clean fossil energy such as gas or transition to renewable energy is two energy scenario that often used by Indonesian government. Traditional solid biomass energy is often excluded in Indonesia government scenario, this is mainly due to no reliable data sources for traditional solid biomass energy which often different from one ministry to another ministry which makes information on biomass energy difficult to be obtained (Biddinika et al., 2016).

Biomass commonly refer to traditional use of solid biomass where the use of solid biomass with basic technologies, such as a three-stone fire, often with no or poorly operating chimneys (IEA, 2018). Based on this IEA definition biomass is not considered as renewable energy. However, energy generated from the conversion of solid, liquid and gaseous products derived from biomass, such as modern solid biomass might be considered as renewable energy.

The sustainability of biomass is important factors to define whether biomass is considered as renewable or non-renewable. In this thesis the non renewable biomass (NRB) is define by the biomass that harvested in excess of the incremental growth rate (Bailis et al., 2015). Based on IPCC's Fourth Assessment, the global of unsustainable woodfuel biomass is estimated at 10%, while in Indonesia the unsustainable biomass is estimated by 43% (Bailis et al., 2015). Analysis in this section distinguishes the emission that based on unsustainable biomass and sustainable biomass.

4.3.3. Geography

Indonesia consists of 17,504 islands of which 2,342 are inhabited by Indonesia’s 261 million population. For analytical purposes these islands are usually divided into six regions (Kuncoro, 2013) or limited to the six biggest islands (Sihombing et al., 2015). The population is divided among Indonesia’s geographical areas as described in Table 4-2.

Table 4-2 percentage of Indonesian population distribution over different island groupings

Scoping	Criteria	Coverage
All islands	All 17,504 islands analyzed.	100.0%
Regional	Regional analysis. All 17,504 islands divided into 6 regions.	100.0%
Top 4	Minimum population of 10 million per islands. Jawa, Sumatra, Kalimantan, Sulawesi.	85.7%
Top 6	Minimum population of 3 million. Jawa, Sumatra, Kalimantan, Sulawesi, Bali, Papua.	87.0%
Top 12	Minimum population of 1 million	93.4%
Top 28	Minimum population of 100 thousand	94.9%

The geography of Indonesia is an important consideration in developing energy transition plans for Indonesia due to the availability of energy resources by island grouping. The development of renewable energy in Indonesia faces many challenges due to the Indonesia's geography. Each of Indonesia's geographical groupings have different renewable energy sources available and the location of the island groupings often means that certain renewable technologies are not feasible. For example, as a tropical country, Indonesia has a high level of solar irradiance which makes Indonesia a perfect place for solar PV energy (World Bank 2017b). However, the distribution of solar power is not distributed evenly. Figure 4 3 shows that based on annual average solar power distribution, solar power has higher potentials in the southern part of Indonesia such as in Java and Bali islands.

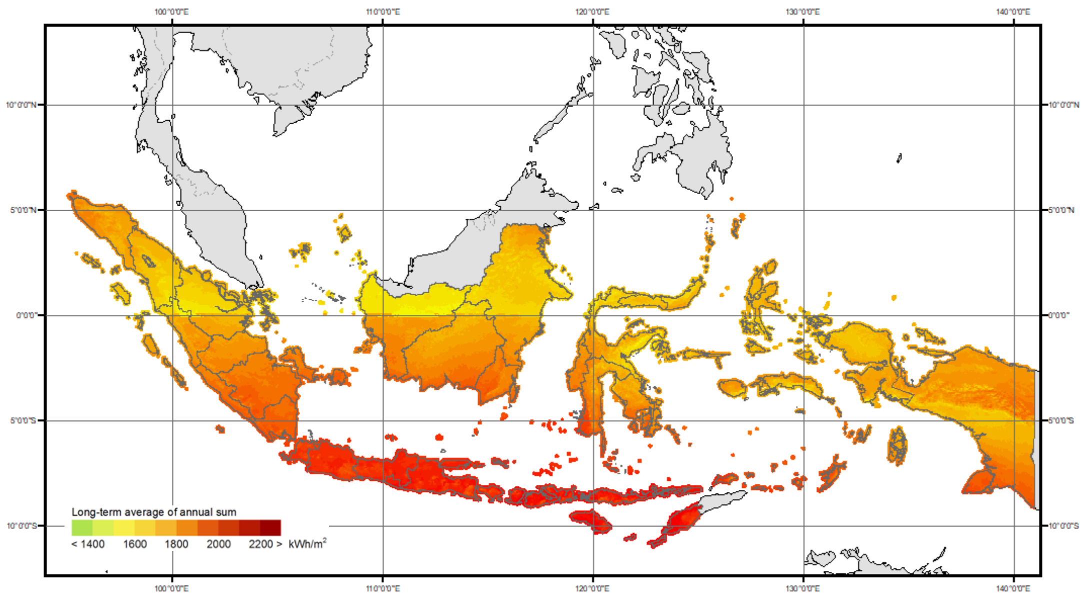

Figure 4-3 Map of annual average solar power potential distributionin KWh/m^2 (World Bank 2017)

Based on the Levelized Cost of Expenditure (LCOE) of solar PV, the cost of electricity from solar PV is too expensive compared with energy from coal-fired power plants (Veldhuis and Reinders, 2013). However, if the economic barriers could be overcome, solar PV could be an effective solution in providing energy access in remote areas where building large coal power plants is not economically feasible, or desirable from a sustainable point of view (Veldhuis and Reinders, 2013).

The wind energy in Indonesia also faces the similar problems as with solar PV. Studies indicate that one of the main constraints in wind energy development is the low level of confidence on the wind availability in Indonesia (Martosaputro and Murti, 2014). For example, the average wind speed in Indonesia is about 4-5 m/s, the higher wind speeds of about 6 m/s are located in the eastern part of Indonesia which is less populated (See Figure 4-4). In comparison, offshore wind speed in the UK might reach 10-11 m/s (Sinden, 2007) (Lu et al., 2009). Even though the eastern part of Indonesia has a higher potential of wind energy the demand of energy in this region is lower compared to western part of Indonesia.

For example, in Nusa Tenggara, an area in Indonesia with strong winds of more than 6 m/s, the remote location makes the development of wind powered renewable energy difficult.

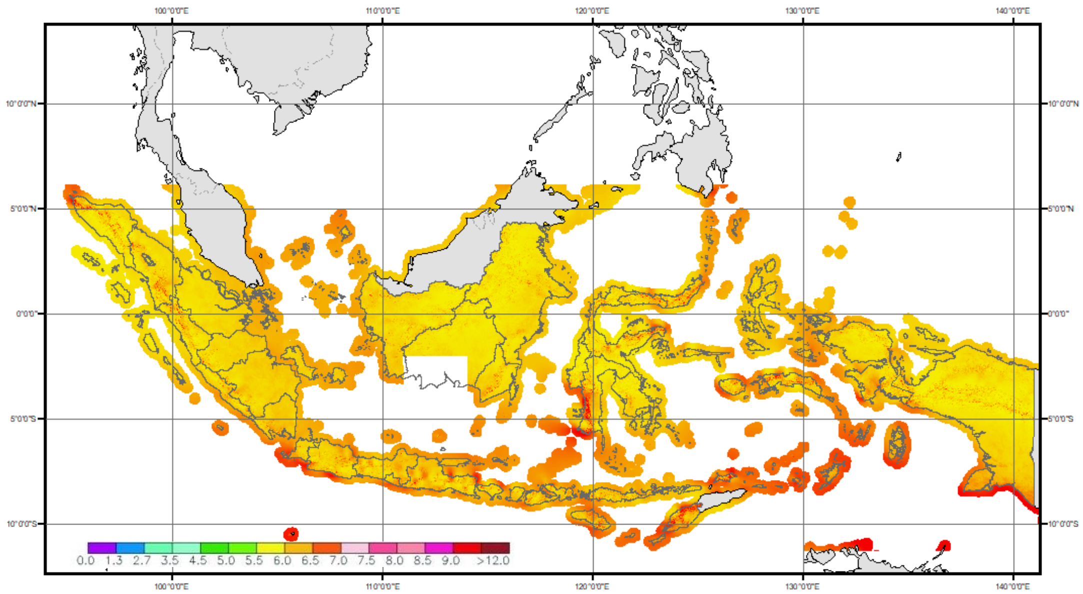

Figure 4-4 Map of annual average wind power potential distribution in m/s (World Bank 2017)

Factors such as intermittent (interruptible) availability and density also affect the feasibility of renewable energy in Indonesia. Solar, wind, and water energy are ‘intermittent’, which mean that the availability and intensity of their energy flows fluctuate at daily and seasonal time scales (Calvert, 2015). The availability of energy, known as the capacity factor, is different from one energy source to another. Solar radiation is only available during the day, the wind is not always available every 24 hours, and there can be a substantial difference between peak and low wind speeds.

The ’density factor’ is also important. Some energy resources have a higher energy density, for example, to generate 1 MW of energy requires a 1000 m^2 of land when using wind turbines, alternatively, nuclear energy requires far smaller land to generate equivalent energy. The density factor also affects the fuel of choice, for example in the transportation sector, biodiesel and other fossil fuels are chosen instead of using electric batteries which have a lower energy density. For example, a lithium-ion battery might have 100 Wh/kg energy density while petrol has 10,000 Wh/kg energy density (Fischer et al., 2009). The higher density factor is preferable in a sense that is more efficient.

Such challenges also exist for fossil fuel energy sources which are similarly unevenly distributed across the island groupings. Historically, it has been seen that areas rich in energy resources such as the gas fields in Aceh and East Kalimantan Province will see a faster pace of development in the surrounding areas than other locations in Indonesia (Ref).

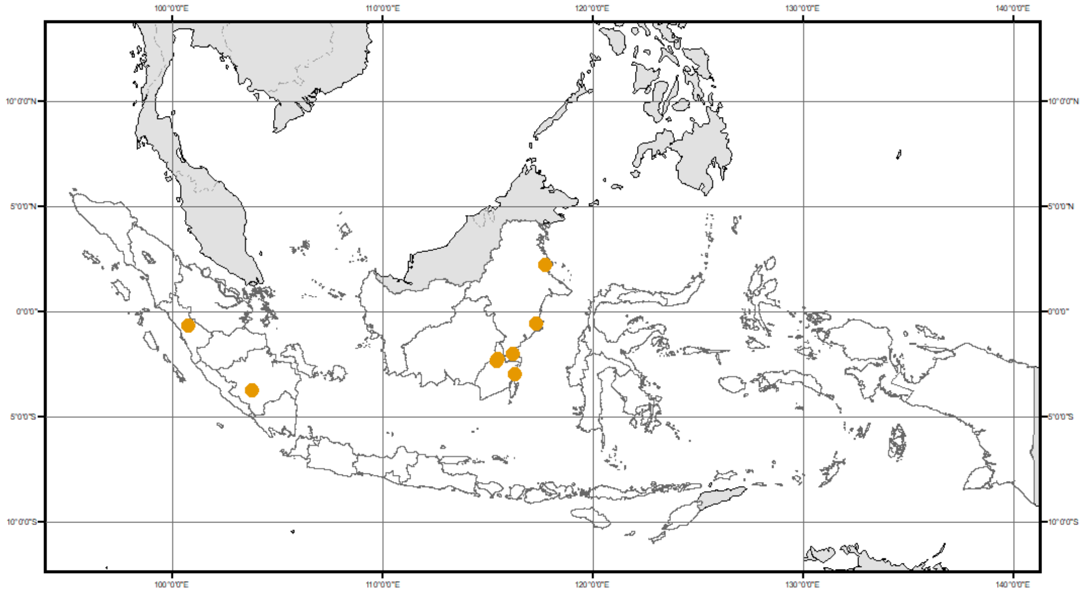

Figure 4-5 Map of coal mining field

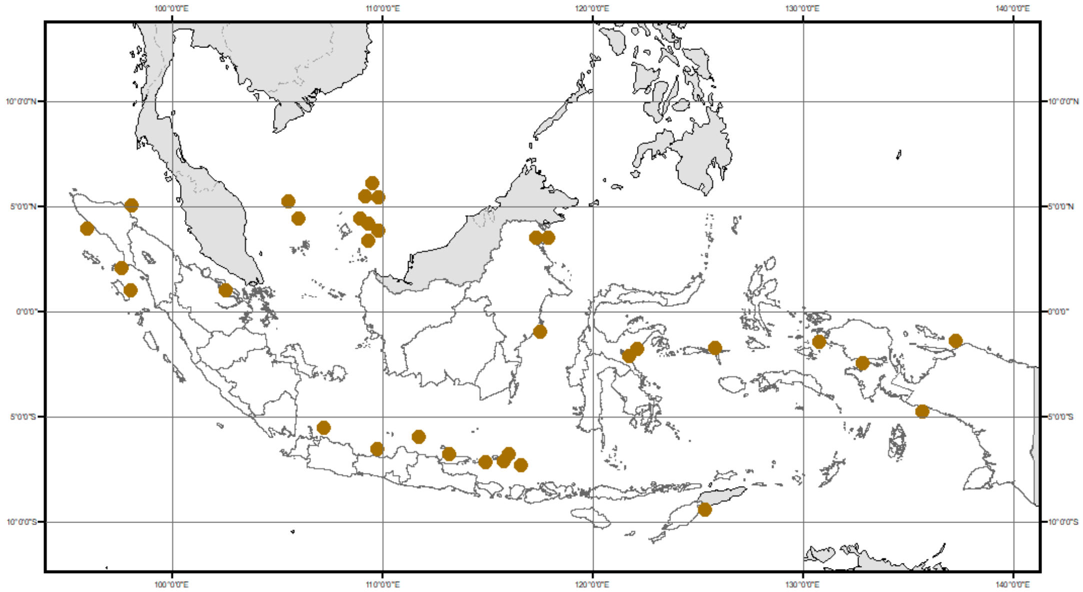

Figure 4-6 Map of offshore oil and gas field

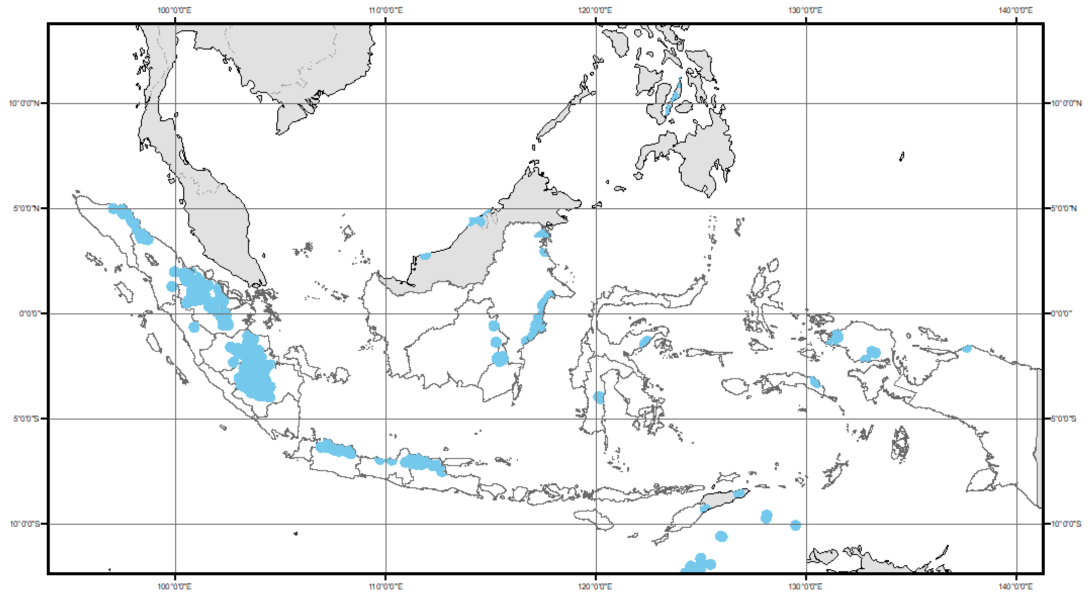

Figure 4-7 Map of onshore oil and gas field

The location of geothermal energy resources (represented by volcanoes) as shown in Figure 4-8 are also unevenly distributed between islands (Hochstein and Sudarman, 2008). Some islands such as Kalimantan although it has abundant coal, gas and oil have no geothermal resources. The average wind speed in the Kalimantan is also the slowest compared with another island.

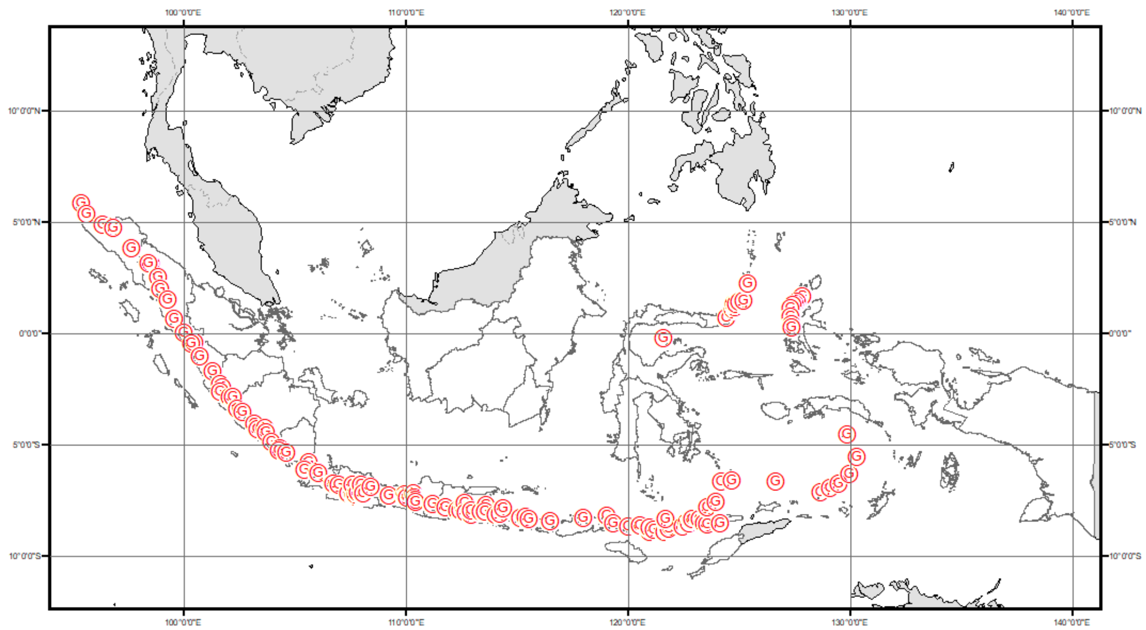

Figure 4-8 Map of geothermal energy sources showing in red circles (Hochstein and Sudarman, 2008)

Similarly, the location of palm oil plantations and land availability for oil palm is shown in Figure 4-9 highlighting that, similar to geothermal energy, renewable energy resources such as biofuels are not distributed evenly across Indonesia (Hansen et al., 2009).

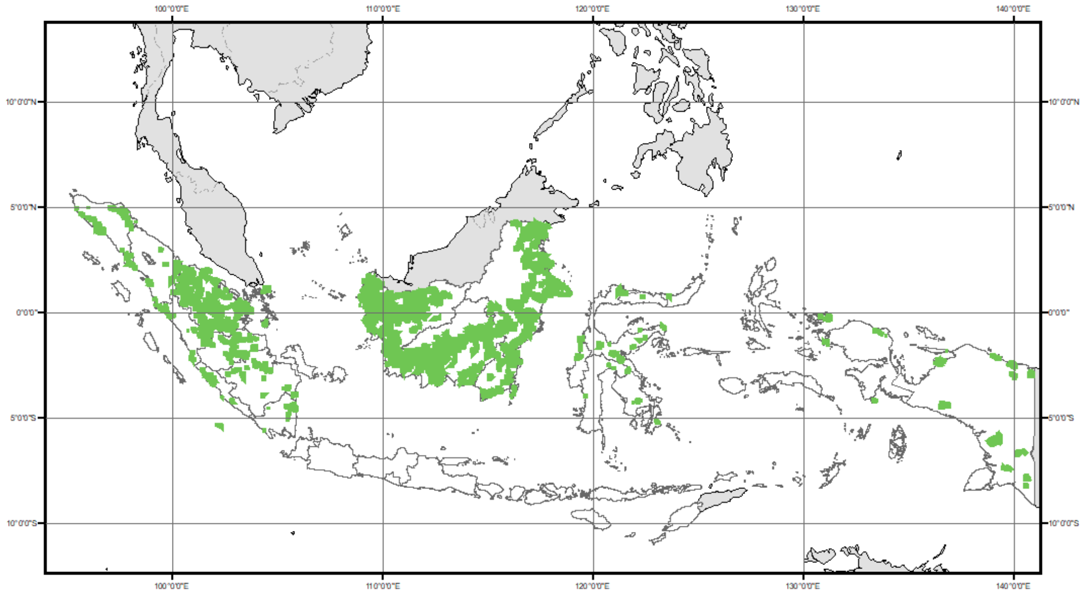

Figure 4-9 Map of palm oil concession showing in green area (Legowo et al 2007)

4.3.4. Accessibility

A city might be supplied by several companies that are sourced by different power generation plants. The use of different source of power generation is to balance the load. This load balancer used to balance the energy consumption that used during peak time. In recent, there are power failures that happens in Jakarta. This situation can be avoided if the power plant is designed to be able to respond to the sudden increase, which should be considering the geographical aspect. Moreover, other factors such as vulnerability to disaster also should be examined carefully. In the case of developing a power plant in the heavily populated area, the risk of fire, due to the electrical problem is relatively high, which makes any electrical company should analyze carefully before deciding to develop its transmission line. The most effective energy development should consider as much as a geographical challenge in the area.

As a country with low energy consumption, government of Indonesia aim to increase the energy consumption and the electrification ratio in their plan. Electrification ratio for example varies from 85% to 60% in certain provinces.

4.4. LEAP IBC Scenario tool

LEAP is an energy policy analysis and climate change mitigation assessment tool widely-used, particularly by developing countries, for energy scenario analysis. The LEAP version that used in this chapter is LEAP-IBC which is a new application of LEAP that incorporates GEOS-Chem adjoint coefficient and GAINS default emissions.

The LEAP-IBC tool is used to calculate the benefits (to human health and near term climate change) of any changes (reductions) in emissions. As such, LEAP-IBC is used to quantify the impacts of air pollutants such as PM on human health and the impacts of both air pollutants and greenhouse gases on climate (as global temperature change) (Heaps, 2018). The impact of air pollutants and greenhouse gases will be described in Chapter 5.

4.5. Scenarios

In this section, three scenarios will be developed using LEAP-IBC to describe three possible futures of Indonesia's energy supply and demand. The baseline (BASE) scenario represents a continuation of current trends in energy mix with fossil fuels featuring heavily and less geothermal and renewable. The Government modified scenario (GOVT) is based on Indonesia's government scenario (mentioned above) and focusses on clean and renewable energy sources. This scenario development is informed by expert opinion that provides insight into what is feasible in relation to technological development and government funding that will change the energy mix in the next decade. The Maximum feasible reduction scenario (MFRE) is maximises renewable energy but considers the limitation of Indonesian geography to ensure that the renewable energy options are feasible. All scenarios are developed considering the impact of forest fire related to biodiesel development.

Expert opinion to modify the GOVT scenario is obtained using semi-structured questionnaires to interview 49 stakeholders that work in sectors related to Indonesian energy provision in 2016 and 2017. The interviews conducted in 2016 (34 interviews) are used to gain an understanding of the current energy situation in Indonesia and to gain insight on how experts perceive the energy system will develop in the future. The interviews in 2017 (15 interviews) are used to adjust the preliminary scenarios developed in 2016. The adjustment using interview is to know the expert opinion on the latest energy scenario. The experts interviewed included representatives from the Indonesian government, businesses and research and development industries in Jakarta, Indonesia. The inclusion of this variety of experts ensured the scenarios developed considered environmental, social and economic sustainability aspects of energy transition.

These scenarios are developed for the period 2010 to 2030. The drivers of change for this time period are GDP, population and technology.

4.5.1. Drivers

The drivers that affecting the growth on these scenario based on the several assumptions. The key assumption for both the baseline and all mitigation scenario is using population growth data from UN projection which are 1.25% from 2010-15, 1.06% for 2015-20, 0.9% for 2020-25 and

0.75% for 2025-30 (UN-DESA, 2017). The economic growth estimates are from the World Bank GDP growth rates which are 5.39% in 2010, 4.87% in 2015, 5.03% in 2016, 5.06% in 2017, 5.24% in 2018, 5.26% in 2019 (World Bank, 2017)

Historical energy consumption and production are taken from the IEA database (IEA, 2014b). The energy export and import composition are assumed to remain the same throughout the modelled period. The supply of energy and sectoral demand from transportation, industry, commercial and residential also remain in the constant proportions. The technological assumption such as power plant efficiency is assumed to remain the same.

4.5.2. BASELINE (2010 – 2030) Scenario (BASE)

The BASE scenario represents a continuation of current historical trend in the energy mix to supply energy demand for Indonesia. In the BASE scenario the energy mix composition is assumed to be remain the same as in 2010. The BASE scenario assumes that the population of Indonesia grows from 243 million in 2010 to 291 million in 2030, and the GDP grows from $755 billion to $2,078 billion over the same period. It also assumes that energy consumption growth is increase from 3.9% in 2014 to 5% in 2030, energy production growth is decrease from -3.2% to -2% in 2030. The assumption of energy production and consumption growth is based on the Indonesia National Development Plan (Bappenas, 2014). Population and GDP is based on UN data (UN-DESA, 2017). In the baseline scenario, it is assumed that no new legislation is developed beyond 2010.

Total primary energy supply (TPES) is the total amount of primary energy that a country has at their disposal. As of 2010, Indonesia's total primary energy supply (TPES) was dominated by oil at 45%, followed by coal at 20%, gas at 25% and renewable energy at less than 10%. This fuel mix composition would be changing due to various factors such as energy production rate, energy price, politics, economic, and social factors

The summary of existing energy scenario represented in term of energy and renewable energy capacity target shown in Table 4-3.

Table 4-3 Existing planned government energy scenario for 2030

Scenario	Energy (Mix)					Renewable (Mix)				
	Oil	Coal	Gas	RE	BM	Geo	Win	Bio.	Hyd	Sol.
1.Baseline (BASE)	34%	15%	18%	8%	24%	90%	0%	0%	10%	0%
2.Planned Renewable (RENGOV)	38%	17%	20%	21%	4%	40%	7%	35%	10%	8%
3.Planned Clean (CLEANGOV)	40%	18%	33%	5%	4%	40%	7%	35%	10%	8%

Note: Renewable Energy (RE), Biomass (BM), Geothermal Energy (Geo), Wind Energy (Win), Biofuel (Bio), Hydropower energy (Hyd), Solar PV (Sol).

The BASE scenario is based on the assumption that the current energy mix remains the same. BASE scenario is a scenario where there is no change in the energy system composition between 2010 and 2030. In developing BASE scenario, the key assumption made is based on government or research institution projection such as population from UN, economic growth estimates from World Bank, historical energy consumption and production from IEA, crop production, vehicle growth rate from Indonesia statistic office. This data is used to estimate the future energy production and consumption.

4.5.3. Government modified Scenarios (GOVT)

The GOVT scenario modifies the Indonesia's government energy scenario with information obtained by conducting stakeholder interviews. The Indonesian government scenarios (RENGOV and CLEANGOV) are modified to reflect a more realistic view of the likely future energy supply mix. This adjustment is made based on stakeholder interviews conducted with Indonesian experts from various energy related sectors. The scenario development process for this analysis uses a combination of literature review and expert interview. The literature review is used to construct the description of future energy scenarios while expert interview is used to validate the description of the scenario.

Two government scenarios are selected for adjustment: renewable energy scenario (RENGOV) which assumes a significant increase of renewable energy, and clean energy scenario (CLEANGOV) which assumes the implementation of additional measures to achieves significant share of natural gas energy.

The purpose of these interviews is to have an understanding of the current energy situation in Indonesia and to gain insight into the future energy system. The result of these interviews are used to inform the development the energy storylines in Indonesia. The semi-structured interview approach was selected for data collection and is described in this section.

The interviews were performed on 20 October – 20 November 2016 with Indonesian representatives from government, business and research development in Jakarta, Indonesia. The representatives is to cover all relevant party that will impact or related to development of energy scenario. The interviewees were selected so as to provide roughly equal representation across three different types of stakeholder as described in Table 4-4 below. This helps overcome bias in the answering of questions that might have occurred were one type of stakeholder to have dominated the stakeholder mix.

The interviews comprised 14 questions. The interviews were performed in two phases. The first phase in November 2016 involving 34 persons and the second phase in September 2017 included 15 persons.

Table 4-4 Semi-structured interview

Group	Sub Group	Interviewees
Operative Business	State Owned Company	4
	Foreign Owned Company	3
	Consultant / Private Company	4
Government and Stakeholder	Energy Department	3
	Finance Department	5
	Others and Regional Department	5
Research and Development	Research Institution	5
	Non-Governmental Organization	5

The stakeholder groups are defiend as follows:- ‘Operative business’ representing major energy players in Indonesia involved state owned companies such as Pertamina and Rekayasa Industry. Foreign owned energy companies in Indonesia represented by major energy companies such as Chevron and Petronas. Consultants involved in thse interviews were international consultant firms such as PricewaterhouseCoopers and Deloitte. ‘Government groups’ that represented in this interview including ministry of energy, ministry of health and ministry of finance. ‘Research and development’ groups represented in this interview including international NGO such as USAid, Asean Energy and WHO. Local research and development representation included researchers in various research institutions and universities.

Semi-structured interview

This section describe the interview questions, how the interviews were conducted, and how the interview data were analysed. There are several approaches that could be used to adjust the scenario including elicitation of experts, generation of large numbers of narratives, or group consensus processes (O’Neill et al., 2014). In this study, the adjustment of the GOVT scenario is made based on qualitative expert interviews and quantitative measurement. We adjust the scenario based on input from the expert representatives gained through interview by asking experts their opinion on barriers and opportunities for the energy development, the questions posed in the semi-structured interview were guided by energy development barrier theory (Painuly, 2001). We asking their opinion and make average based on this opinion.

The questionnaire used in this interview was based on the ‘Barriers to renewable energy penetration framework’ (Painuly, 2001) and the ‘Multilevel perspective theory’ (Geels, 2002). This framework is used as a guideline in the generating the questions used during the interview process.

Experts were also asked on their opinion on the future share of clean and renewable energy in the energy mix. In each interview, an expert is asked about their opinions on the future state of the energy system in Indonesia. Each expert gives their opinion on the growth of each fuel in the future energy system and further the experts adjusted the energy share based on their analysis. The representative would be asked their opinion on the likely future energy mix composition (as percentages) in Indonesia, what energy type that will be dominating and the timeline to achieve this composition. Later the final energy mix composition is based on the average of local expert opinion on future energy mix. The results of these interviews are a more realistic quantification of the energy mix.

The detail list of question shown in Table 4-5 below.

Table 4-5 Semi-structured interview used in 2016 to interview 34 stakeholders of Indonesia energy systems

Area	**Questions**
Landscape-level (macro, international)	
Political System	How far do the government regulation affecting for future energy mix
Decision Making	To what extent are the official decision-making affecting energy development
Long Term	What are the key governance effects of energy production
Climate Change	Is the climate change agenda considered in the political decision-making on energy developments?
Regime Level (meso, national)	
Prospect (Opportunity vs challenge)	
Technological	To what extent are renewable and clean energies affecting conventional fossil fuel power plant development
Market conditions	Is there any system of renewable energy promotion in place
Socio-cultural	How widespread is the knowledge of renewable energies in Indonesia?
Labor markets	Is the job creation potential actually employed by promoters of renewable electricity in the country?
Policy	
Policy regime	Is there a strategic document, such as an energy roadmap/blueprint or at least a non-binding planning scheme? If so, how does this integrate renewable electricity?
Governance bodies	Do the regional electricity governance bodies promote political or infrastructure projects that enhance the role of renewable electricity in the target country? Is external demand a pull factor in that respect?
Subsidies	Are strategies developed to create a level playing field for all types of energy carriers (by removing subsidies for conventional power or by integrating renewable electricity into the existing subsidy schemes)
Niche-level (industry specific)	
Science regime	Is there an attempt to create a domestic knowledge center for renewable energy
Technology transfer	Is there an industry structure that supports the spread of technologies into mainstream society?
Technological developments	What is the opinion on technology choices and on the chance of industry- use of renewable energy as entry points for further development

To understand the likelihood of these two scenarios, an additional interview is performed in September 2017 to understand the opportunities and barriers for this scenario. Further this second interview aims to estimate the possible fuel mix composition in the future. The persons that interviewed in this second period are described in Appendix. The questions on opportunities and barriers for energy scenario is based on Painuly's Renewable Energy Penetration Framework (Painuly, 2001) shown in Table 4-6.

Table 4-6 List question 2017

Area	Questions
Renewable energy scenario	
Opportunities	Socio-economic development, what is the current state of renewable energy in Indonesia. What is the significant socio-economic factors e.g poverty
	Energy access. How might energy access affect the renewable energy demand
	Energy security, how availability of energy affects renewable energy development
	Climate change mitigation. How will efforts to reduce GHG emission affect renewable energy policies
Barriers	Market conditions, what is the state of the renewable energy market in Indonesia. What is latest market conditions in Indonesia.
	Awareness and sociocultural barriers, how much awareness of stakeholder (e.g government and business) is there of renewable energy
	Policy barrier, subsidies, governance, how policy might affect renewable energy development
	Technological barrier, how technology might affect renewable energy development
Dimension	Fuel Mix, Type of Fuel, Timeline (all by sectors). What would define boundary of scenario
Clean energy scenario	
Opportunities	Socio-economic development, what is the current state of natural gas energy in Indonesia
	Energy access. How might energy access affect natural gas demand
	Energy security, how availability of energy affects natural gas energy development
	Climate change mitigation. How will efforts to reduce GHG emission affect natural gas energy policies
Barriers	Market conditions, what is the state of natural gas energy market in Indonesia
	Awareness and sociocultural barriers. How is awareness (of stakeholders e.g government, business) of natural gas energy. How stakeholders thought about clean energy growth in Indonesia
	Policy barrier, subsidies, governance, how might policy affect natural gas energy development
	Technological barrier. How might technology affect natural gas energy development
Dimension	What is the likely fuel Mix, Type of Fuel, Timeline (all by sectors) that would be associated with a clean energy scenario

Summary of expert opinion is used to modify the initial scenario. The result of this final adjustment will be used to develop the final scenario. The expert will ask in the interview and the result of the adjustment will be compiled based on average number.

4.5.4. Maximum feasible reduction (MFRE) Scenario

MFRE scenario is a maximum feasible reduction scenario that describes a future in which use of Indonesia's potential renewable energy resources is maximised. This scenario takes into account the unique geography of Indonesia and assumes that all the potential renewable energy sources are identified and exploited where appropriate according to the particular island characteristics. The potential energy data used in this analysis are based on IEA (IEA, 2014a) and MEMR data (MOEMR, 2017) for the potential energy resources data.

A geographical analysis can be made using either a regional analysis or islands analysis. A regional analysis is based on the number of region in Indonesia which are six region. An island analysis is based on number of island in Indonesia which are 17,000 islands. An islands analysis might provide a more accurate analysis due to the uniqueness of the geographical feature. On the other hand, the regional analysis can be used to simplify the geographical feature of Indonesia which can be divided into six regions. The regional analysis would be more useful if it is used to understand the regional impact analysis at the regional or province level. For example, the regional analysis would only analysis Indonesia from six regional group or based on 33 provinces that is limited compare to all island analysis.

MFRE formulation can be made by considering island's unique renewable energy resources. MFRE is calculated based on maximum renewable energy supply that can be produced on each island. The energy mix island factor, which describe the distribution of energy in percentage was compiled from Indonesia Ministry of Energy (Fujimori et al., 2017), (MOEMR, 2017). The formula for maximum feasible renewable energy calculation is as follows:

$$\boldsymbol{TPES} = \sum_{\boldsymbol{i}} \{ \boldsymbol{E_i} \times \boldsymbol{MF_i} \} \qquad \text{(Equation 1)}$$

TPES = Total Primary Energy Supply
i = Energy type
E = Energy production (Assuming that all energy type produces at maximum capacity)
MF = Energy mix factor of energy production

$$\boldsymbol{MIRES} = \sum_{\boldsymbol{i,j}} \{ \boldsymbol{E_i} \times \boldsymbol{MIF_{i,j}} \} \qquad \text{(Equation 2)}$$

MIRES = Maximum Island Renewable Energy Supply
i = Energy type
j = Islands

E = Energy production (Assuming that all energy type produces at maximum capacity)

MIF = Energy mix factor of energy production for each island

$$\sum_{i,j} \left(\frac{MF}{E}\right) = 1 \qquad \text{(Equation 3)}$$

MF = Energy mix factor

Location analysis aims to identify the maximum amount of energy transition that is possible considering the uniqueness of island's source of energy as shown in Table 4-7 (MOEMR, 2017). The maximum potential energy per islands is based on Ministry of Energy analysis (MOEMR, 2017). The total maximum potential energy that can be achieved for Indonesia based on 2010 analysis is 550 Mtoe. The maximum potential energy is sufficient to supply all the energy consumption in 2030 which estimated to be 400 Mtoe. This means that, in theory, 100% transition to renewable energy in Indonesia is possible (MOEMR, 2017).

Table 4-7 Maximum potential energy in Mtoe

Islands	Geoth	Wind	Biofuel	Hydro	Solar	Total
Sumatra	12.7	0.8	11.7	11.7	103.1	140.0
Java	8.6	2.9	6.9	3.2	29.1	50.8
Kalimantan	0.0	0.0	3.8	16.2	112.0	132.1
Bali	2.8	1.5	1.0	4.1	25.1	34.4
Sulawesi	4.6	2.9	2.0	8.1	50.2	67.8
Papua	1.3	0.2	1.0	17.1	105.9	125.6
Total	30.0	8.3	26.4	60.5	425.5	550.7

However, achieving 100% renewable energy transition means each region would have a different type of energy transition. Based on this, the link between maximum potential for renewable energy with the maximum energy transition can be established. It means that any target for maximum energy transition should consider maximum potential renewable energy in each island.

To create the maximum feasible reduction per islands the following method is used. First, an island or region assumed should use all available renewable energy resources. Second, priority of renewable energy should follow Indonesia government priority which are geothermal, biofuel, hydro, wind and solar PV. For an island with no certain renewable energy such as Kalimantan which has no geothermal the priority should be given to the next available sources. This analysis also avoids simplification of energy transition scenario that can be simply achieved by using 100% solar PV. This analysis also ensures that all types of potential renewable energy sources are covered.

4.6. Results - scenarios

4.6.1. BASELINE Scenario

The BASELINE Scenario result as follows.

Table 4-8 Energy emission baseline scenario

Scenario	Sectors	Base-year (2010)	Scenario description by 2030
BASE	Residential Cooking	29% LPG, 39% stove wood, 22% electricity, 8% kerosene (in share of people)	Remain the same
	Electricity generation	48% natural gas, 24% coal, 11% diesel, 14% renewable	Remain the same
	Industry	Steel industry 41% natural gas, 22% gas diesel oil, 37% heavy fuel oil. Other industry 29% Coal, 25% Natural Gas, 13% Gas diesel oil, 14% primary biomass, electricity 10%. Brick and tile kilns industry 100% other coal.	Remain the same
	Road Transport	64% motor gasoline, 36% gas diesel oil	Remain the same

4.6.2. Government modified Scenarios

4.6.2.1 Results - Qualitative interview

This section describes the result of the interviews that have been conducted with Indonesian representatives from government, business and research development in Jakarta, Indonesia. The results of the 2016 interview are grouped based on the area of landscape, regime and niche level. The highlight based on the interview shown below.

Landscape level

Landscape is covers political system, decision making, long term and climate change.

Q1.1 Political system

Question: “How far do the government regulation affecting for future energy mix particularly on renewable and clean energy”

In 2006 Government of Indonesia release presidential regulations on the future share of renewable energy mix in national energy system. The development of this policy is affecting the composition of energy mix in the country. In 2014, this regulation is updated. National Energy Council (DEN) was established in 2007. This government body formulated the future energy mix composition.

One interviewee confirms this notion saying

“*Government regulation is significantly important. Currently Indonesian government support on the development of renewable and clean energy. Indonesian government see that the current* *energy development and utilization is very low. It is indicated by lack regulation and incentive for renewable and clean energy*"

Q1.2 Decision making

Question: "To what extent the official decision-making affecting energy development"

The history of energy development in Indonesia has high involvement of the government. From earliest oil exploration in 1960s, early geothermal exploration in 1980s to biofuel development in 2000s. The development of renewable energy such as geothermal energy for example is mainly subsidized by government (Hochstein and Sudarman, 2008).

One interviewee stating

"*Government has the biggest bargaining power for energy development from tariff to land permit, its decision will have affected various of energy development. Economic feasibility of the energy project will depend on the government policy*"

Q1.3 Long term

Question: "What is the long-term role of governance in the energy production"

In 2002, Indonesia created several bodies such as Task force for upstream oil and gas business activities (SKK Migas) that regulating the upstream energy industry (Purwanto et al., 2016). Another body, Governing body of downstream oil and gas agency also established in 2002 to regulate the downstream energy industry

One interviewee stating

"*Governance aspects is very important, Indonesian government try to reduce conflicting policy between ministry that often happen in the past, the government begin to synchronize all the energy policy. In the past, there is possibility that ministry level policy might conflicted, but with the establishment of agency such SKK Migas or Renewable energy directorate this conflict can be reduced. In the long term, the governance aspect will be improved*"

Q1.4 Climate change

Question: "Is the climate change agenda considered in the political decision-making on renewable energy developments?"

One interviewee stating

"*In general, most of renewable energy policy is align with climate change agenda. Therefore, we are not worried. However, in some cases the energy and environment policy often* *conflicting, especially that coming from different directorate. In oil and gas directorate for example, this conflict often happens*"

Q1.5 Section conclusion

Political system is the most crucial factor that driving the energy policy in Indonesia. Energy policy from the ruling government has the biggest influence in the energy development in Indonesia. Any energy policy should be aligned with the government prioritization in order to be implemented successfully. For example, between energy access increase and energy emission reduction. Integrated policy planning to avoid the conflict from related ministry or government office should be prioritized.

Regime level

Regime level is about the prospect of energy development and the policy of energy development in Indonesia. From the perspective of energy policy, the energy growth in Indonesia reflects the decreasing roles of oil energy and increasing roles of coal and gas. In the early of 1980 there are changes in the increased roles of coal and gas which affected by various factor from globalization to economic factor. The composition of renewable energy is still small compare with other fossil fuel energy. The period of 1980 is a period where the national energy planning is started to be formalized and monitored. Indonesia as part of national planning has national energy policy developed in 1981, 1987, 1991, 1998 and 2003. The policy strategy is to focus on energy diversification, energy efficiency and to ensure the energy access and security.

Q2.1 Technological

Question: "To what extent are renewable energies affecting conventional fossil fuel power plant development"

One interviewee stating

"*We are the energy company. We have directorate in renewable energy, so we are ready for renewable energy. I think most of energy company realize this situation*"

However, most of the technology and expertise is not from the local, as Indonesian does not have the enough technology and expertise capability. One interview mention that

"*Most of renewable technology is expensive to be implemented, therefore in the future most likely will be not feasible. Fossil fuel in Indonesia is cheaper*"

Q2.2 Market conditions

Question: "Is there any system of renewable energy promotion in place"

One interviewee that works in state owned enterprise (SOE) of engineering and construction company (EPC) stating

"*Renewable energy is attracting number of investors from US, Japan and Europe but we are local people not paying attention. It should be promising, but we just not realized the importance of this*"

Q2.3 Socio-cultural

Question: "How widespread is the knowledge of renewable energies in Indonesia?"

One interviewee stating

"*People seems not aware with renewable energy, there are many cases that people did not know the differences between gas energy and renewable energy*"

Q2.4 Labour markets

Question: "Is the job creation will rise by the development of renewable electricity in the country?"

One interviewee in government SOE EPC mention that

"*There are number of investors, that would like to work and bid for working project in energy, therefore the job creation will significantly be raised*"

Q2.5 Policy regime

Question: "Is there a strategic document, such as an energy roadmap/blueprint? If so, how does this integrate renewable energy?"

One interviewee that works as researcher in university mention that

"*We have the policy and plan for renewable energy, but on the practical level it is difficult to integrate with other policy*"

Q2.6 Governance bodies

Question: "Do the energy government bodies promote projects that enhance the role of renewable or clean energy in the country?"

One interviewee in government department mention

"*The regulator is better now, we are working according to the regulation to achieve certain energy mix; we are working to achieve the renewable share mix by doing assistance and promotion of renewable energy*"

Q2.7 Subsidies

Question: “Are strategies developed to create a level playing field for all types of energy sources? by removing subsidies for conventional power or by renewable and clean energy into the existing subsidy schemes”

One interviewee mention that

“*There are a lot of strategy that inappropriately given. Some subsidy is not reaching the target. However, at this moment subsidy is important factors in every renewable and clean energy. We give like tax reduction to easier process for energy permit*”

Q2.8 Section conclusion

The prospect of energy development in Indonesia is big. It is indicated by a technological development of the energy that suitable for Indonesia, there are a several investors that willing to invest in the renewable energy Indonesia. Government of Indonesia allocating its bodies and developing policies that supporting renewable and clean energy development.

Niche level

Niche level are covers technology development of energy in Indonesia and act as starting point of development of renewable and clean energy in Indonesia.

Q3.1 Science regime

Question: “Is there an attempt to create a domestic knowledge centre for renewable and clean energy in Indonesia”

One interviewee mention that

“*There are non-governmental organization that working for capability building of energy in Indonesia for example in developing micro wind turbine or biofuel. A start-up company also built to promote the use of renewable energy*”

One interviewee that works as researcher in university mention that

“*There is research of various source of energy available in Indonesia, but difficult to expand, especially in the business and economics aspect of selling renewable energy which tend to be more expensive*”

Q3.2 Technology transfer

Question: “Is there an industry structure that supports the spread of technologies into mainstream society?”

One interviewee that works as researcher in university mention that

"*Industry structure as a whole is not ready, for example infrastructure for electric car is not ready. Solar PV industry is not ready, most of solar PV panel is imported. Market seems promote any technology that cheaper where in most cases is fossil fuel. Energy infrastructure such as electricity grid also an effective way to promote renewable energy*"

Q3.3 Technological developments

Question: "What is the opinion on technology choices and on the chance of industry use of renewable energy or clean energy as entry points for further development"

One interviewee mentions that

"*Renewable energy Indonesia is difficult to be achieve, however clean energy such as gas would have a bigger chance. Capital is the biggest obstacle for energy development in Indonesia. Energy development is not a cheap initiative*"

Q3.4 Summary of interviewes

Clean energy development has a bigger chance compare with the renewable energy. In term of research, renewable energy has good foundation, however, to upsize as the industry is difficult. The niche for certain energy technology would be effective where it has a strong industry support such as natural gas or biofuel. The prospect of renewable energy such as solar PV or wind energy is not as good compare with clean energy such as natural gas or biofuel.

It has been demonstrated that the main driver for energy system development in Indonesia is mainly government driver, whether it comes from energy policy or involvement of state-owned company in energy project. It can be explained that the opportunity of energy development in term of technology and market is promising. Interview also explaining that the niche development for renewable energy is difficult as industry is not ready. It is suggested that clean energy would plays bigger role in the niche development.

Interview view Indonesia's future energy scenario is varied. Based on the scenario development, it can be concluded that even though renewable energy is becoming priority however its industry is not supporting. It also to be noted that with the specific strategy on renewable share, the implementation of this policy is not likely to be successful. Any energy scenario that supported by government in term of policies and the act of state-owned enterprise in executing the strategy would be the most effective scenario. In general, government is the biggest enablers for energy transition in Indonesia, whether it is transition to renewable energy or transition in to clean energy. The second biggest enabler is the infrastructure, for example the development of renewable energy might be more effective by developing the electricity grid. Capital would be the biggest obstacle of energy development in Indonesia, this require a subsidy from Indonesian government to grow. Energy transition question that used in the interview is based on Geels Multi-Level Perspective framework (Geels, 2002).

Based on the interview, it has been demonstrated that the main driver for energy system development in Indonesia is the government, whether it comes from energy policy or involvement of state-owned company in energy projects. It should be noted that the opportunity for energy development in terms of technology and market is promising. The interviews also indicated that the niche development for renewable energy is difficult as industry is not ready. It is suggested that clean energy would plays bigger role in the niche development.

The interviewees' view of Indonesia's future energy scenario is varied. Based on the interview, it can be concluded that even though renewable energy is becoming a priority, its industry is not supporting, and the government is also not showing the commitment for renewable energy development. It is also to be noted that with the specific strategy on renewable share, the implementation of this policy is not likely to be successful. Any energy scenario that included the support of government in terms of policies and the actions of state-owned enterprise in executing the strategy would be the most effective scenario.

The Indonesian government is the biggest enabler for energy transition in Indonesia, whether it is transition to renewable energy or transition in to clean energy. The second biggest enabler is the infrastructure, for example the development of renewable energy might be more effective by developing the electricity grid. Capital would be the biggest obstacle of energy development in Indonesia, this require a subsidy from Indonesian government to grow. Based on interview in October 2016 from 34 persons, at least there are two possible future state for Indonesia fuel mix, shown in Table 4-9. Further government energy scenario should be adjusted to reflect the current situation in Indonesia.

Table 4-9 Energy scenario description

Name	**Storyline description**
Scenario 1: Renewable energy	• Indonesia aims to increase the share of renewable energy to 23% by 2025 (25% by 2030) • Opportunity for energy development in terms of technology and market is promising. State-owned company will be the main driver for renewable energy project. • National Energy Policy (NEP) 2014 policies will be key policies in the future
Scenario 2: Clean energy	• Indonesia aim to increase the share of gas to 30% by 2025 (33% by 2030) • Industry is not supporting, and the government is also not showing the commitment for renewable energy development • National Gas Roadmap (NGR) 2014 will be driving policy in the future

4.6.2.2 Results - Adjusted fuel mix

Adjusted scenario is based from interview with energy stakeholder in Indonesia. Table 4-10 below summarized the adjustment of energy scenario based on average input of each interviewee. Each of interview give their opinion on the opportunities and barrier of each energy scenario.

Table 4-10 Adjusted energy production growth scenario

		Energy growth			
No	**Adjusted Scenario**	**Oil**	**Coal**	**Gas**	**RE**
1	Interviewee 01	Slow	Slow	Rapid	Slow
2	Interviewee 02	Slow	Slow	Rapid	Negative
3	Interviewee 03	Slow	Negative	Slow	Negative
4	Interviewee 04	Slow	Rapid	Slow	Slow
5	Interviewee 05	Slow	Rapid	Slow	Rapid
6	Interviewee 06	Slow	Rapid	Rapid	Slow
7	Interviewee 07	Slow	Negative	Rapid	Slow
8	Interviewee 08	Slow	Slow	Rapid	Rapid
9	Interviewee 09	Slow	Slow	Slow	Negative
10	Interviewee 10	Slow	Slow	Slow	Negative
11	Interviewee 11	Slow	Slow	Slow	Rapid
12	Interviewee 12	Slow	Rapid	Slow	Slow
13	Interviewee 13	Slow	Negative	Slow	Rapid
14	Interviewee 14	Slow	Slow	Slow	Slow
15	Interviewee 15	Slow	Slow	Slow	Slow

Based on energy mix (energy composition) scenario, each interviewee was asked to comment on the estimated future energy mix in 2030, the results are summarized in Table 4-11 below. The final energy mix that was used for the GOVT scenarios was derived from the average of each interviewees answer to this questions..

Table 4-11 Adjusted energy mix share scenario

		Share of energy mix			
No	**Energy Mix**	**Oil**	**Coal**	**Gas**	**RE**
1	Interviewee 01	40%	18%	33%	9%
2	Interviewee 02	42%	19%	35%	5%
3	Interviewee 03	53%	12%	29%	6%
4	Interviewee 04	41%	27%	23%	9%
5	Interviewee 05	39%	26%	22%	13%
6	Interviewee 06	37%	24%	31%	8%
7	Interviewee 07	30%	20%	40%	10%
8	Interviewee 08	25%	20%	40%	15%
9	Interviewee 09	47%	21%	26%	5%
10	Interviewee 10	47%	21%	26%	5%
11	Interviewee 11	41%	18%	23%	18%
12	Interviewee 11	41%	27%	23%	9%

13	Interviewee 12	47%	11%	26%	16%
14	Interviewee 13	45%	20%	25%	10%
15	Interviewee 14	45%	20%	25%	10%

The interview data described above is used to revise two government energy scenarios leading to the development of scenarios that provide more realistic estimation on the future share of energy in Indonesia. These two scenarios are: Adjusted renewable energy scenario (RENEW) and Adjusted clean energy scenario (CLEAN) summarized in Table 4-12.

Table 4-12 Final scenarios for 2030

SCENARIO	ENERGY (MIX)					RENEWABLE (MIX)				
	Oil	**Coal**	**Gas**	**RE**	**BM**	**Geo.**	**Win**	**Bio.**	**Hyd**	**Sol.**
1.Baseline (BASE)	34%	15%	18%	8%	24%	90%	0%	0%	10%	0%
2.Adjusted Renewable (RENEW)	33%	16%	24%	14%	13%	40%	7%	35%	10%	8%
3.Adjusted Clean (CLEAN)	37%	18%	25%	7%	13%	40%	7%	35%	10%	8%

Further each scenario is translated in each subsector as summarized in Table 4-13.

Table 4-13 Scenario element

Name	**Scenario Element**
Scenario 1: Renewable Energy	• GDP, Population, Consumption and Production Growth • Electricity sector to increase the share of renewable from 5% in 2010 to 23% by 2025 • Transportation sector to increase biodiesel share from 3% in 2010 to 20% by 2025 • Household sector to increase biogas share • Industry sector to increase renewable share in industry
Scenario 2: Clean Energy	• GDP, Population, Consumption and Production Growth • Electricity sector to increase the share of natural gas from 20% in 2010 to 30% by 2025 • Transportation sector to increase CNG based vehicle share • Household sector to increase LPG share from 10% in 2010 to 40% by 2025 • Industry sector to increase natural gas share

Table 4-14 described detail by sectors scenario

Table 4-14 Detailed scenario by sectors

SCENARIO	ENERGY (MIX)					RENEWABLE (MIX)				
	Oil	**Coal**	**Gas**	**RE**	**BM**	**Geo.**	**Wind**	**Bio.**	**Hydro**	**Solar**
BASE	34%	15%	18%	8%	24%	90%	0%	0%	10%	0%
i.Electricity	19%	45%	22%	14%	0%	90%	0%	0%	10%	0%
ii.Industry	22%	33%	33%	12%	0%	90%	0%	0%	10%	0%
iii.Transport	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
iv.Residential	8%	0%	0%	0%	92%	0%	0%	0%	0%	0%
RENGOV	38%	17%	20%	21%	4%	40%	7%	35%	10%	8%
i.Electricity	19%	34%	22%	25%	0%	62%	4%	20%	9%	5%
ii.Industry	22%	21%	33%	25%	0%	50%	3%	33%	10%	4%

iii.Transport	75%	0%	0%	25%	0%	0%	0%	100%	0%	0%
iv.Residential	8%	0%	0%	77%	15%	9%	2%	80%	6%	3%
CLEANGOV	40%	18%	33%	5%	4%	40%	7%	35%	10%	8%
i.Electricity	41%	19%	35%	5%	0%	62%	4%	20%	9%	5%
ii.Industry	41%	19%	35%	5%	0%	50%	3%	33%	10%	4%
iii.Transport	75%	0%	25%	0%	0%	0%	0%	0%	0%	0%
iv.Residential	8%	0%	77%	0%	15%	0%	0%	0%	0%	0%
RENEW	33%	16%	24%	14%	13%	40%	7%	35%	10%	8%
i.Electricity	19%	45%	22%	14%	0%	62%	4%	20%	9%	5%
ii.Industry	22%	33%	33%	12%	0%	50%	3%	33%	10%	4%
iii.Transport	75%	0%	0%	25%	0%	0%	0%	100%	0%	0%
iv.Residential	8%	0%	0%	44%	49%	9%	2%	80%	6%	3%
CLEAN	37%	18%	25%	7%	13%	40%	7%	35%	10%	8%
i.Electricity	38%	19%	36%	7%	0%	62%	4%	20%	9%	5%
ii.Industry	38%	19%	36%	7%	0%	50%	3%	33%	10%	4%
iii.Transport	75%	0%	25%	0%	0%	0%	0%	0%	0%	0%
iv.Residential	8%	0%	44%	0%	49%	0%	0%	0%	0%	0%

4.6.3. MFRE Scenario

The summary of energy emission scenario for each sector shown in Table 4-15 below.

Table 4-15 Energy emission scenario summary

Scenario	**Sectors**	**Base-year (2010)**	**Scenario description by 2030**
BASE	Residential Cooking	29% LPG, 39% stove wood, 22% electricity, 8% kerosene (in share of people)	Remain the same
	Electricity generation	48% natural gas, 24% coal, 11% diesel, 14% renewable	Remain the same
	Industry	Steel industry 41% natural gas, 22% gas diesel oil, 37% heavy fuel oil. Other industry 29% Coal, 25% Natural Gas, 13% Gas diesel oil, 14% primary biomass, electricity 10%. Brick and tile kilns industry 100% other coal.	Remain the same
	Road Transport	64% motor gasoline, 36% gas diesel oil	Remain the same
CLEAN	Residential	29% LPG (in share of people)	35% LPG (kerosene decline to 3%)
	Electricity	48% natural gas	55% natural gas (sub bituminous coal decline to 16%)
	Industry	41% natural gas	55% natural gas (heavy fuel decline to 23%)
	Road Transport	0% natural gas	35% natural gas (motor gasoline decline to 29%)
RENEW	Residential	0% renewable share of people	25% renewable (stove wood decline to 14%)
	Electricity	14% renewable	25% renewable solar and wind (sub bituminous coal decline to 9%)
	Industry	0% renewable	25% renewable solar and wind (natural gas decline to 15%)
	Road Transport	0% biodiesel	25% renewable biodiesel (gas diesel oil decline to 10%)
MFRE	Residential	As for BASE scenario	100% renewable
	Electricity	As for BASE scenario	100% renewable
	Industry	As for BASE scenario	100% renewable
	Road Transport	As for BASE scenario	100% renewable (64% electric, 35% biodiesel)

Based on maximum potential source of energy we developed the final maximum reduction islands scenario as shown in Table 4-16.

Table 4-16 Renewable energy mix share per islands in MFRE scenario

Scenario	Geoth	Wind	Biofuel	Hydro	Solar	Total
Maximum Reduction (MFR) 2030	5%	2%	5%	11%	77%	100%
i.Sumatra	9%	1%	8%	8%	74%	100%
ii.Jawa	17%	6%	14%	6%	57%	100%
iii.Kalimantan	0%	0%	3%	12%	85%	100%
iv.Bali	8%	4%	3%	12%	73%	100%
v.Sulawesi	7%	4%	3%	12%	74%	100%
vi.Papua	1%	0%	1%	14%	84%	100%

Further MFRE scenario should consider that availability of biofuel energy in each island. MFRE based on biofuel energy mix as shown in Table 4-17.

Table 4-17 Biofuel energy mix share in MFRE scenario

Scenario	Bio Diesel	Bio Ethanol	Solid BM	Biogas	Total
Baseline (BASE) 2030	0%	0%	0%	0%	0%
Maximum Reduction (MFR) 2030	39%	24%	35%	2%	100%
i.Electricity	-	-	30%	-	-
ii.Industry	-	-	50%	-	-
iii.Transport	100%	100%	-	-	-
iv.Residential	-	-	20%	100%	-
v.Other	-	-	-	-	-

Maximum feasible reduction assumes that a 100% transition to renewable energy can be achieved as shown in Table 4-18. This scenario assumes that the use of fossil fuel (oil, coal, and natural gas) and traditional solid biomass are phased out and replaced by renewable energy.

Table 4-18 MFRE energy scenario

Scenario	Energy (Mix)					Renewable (Mix)				
	Oil	Coal	Gas	RE	BM	Geo.	Win	Bio.	Hyd	Sol.
1.Baseline (BASE)	34%	15%	18%	8%	24%	90%	0%	0%	10%	0%
2.Max Reduction (MFRE)	0%	0%	0%	100%	0%	5%	2%	5%	11%	77%

Adjusted ‘realistic’ emission scenarios for Indonesia have been developed based on current Indonesian government scenarios. The current Indonesian government scenarios focus on increased use of either clean energy or renewable energy, as alternative means of achieving a sustainable energy transition. To reflect the current situation, an adjustment of capacity targets has been made by based on the outcome of expert interviews.

It also needs to be noted that other geographical aspect of energy transition that might affects emission scenario development. In this chapter previously, the only energy geography indicator considered in developing the energy scenarios was the amount of potential energy. In emission scenario development for a country such as Indonesia, geographical features are crucial factors that should be considered in the analysis. In this section, the geographical analysis dimension is based on energy geography dimension developed by Bridge (Bridge et al., 2013).

Analysis is made to understand the relation of this geographical dimension with future energy development by comparing various indicator with the growth rate of energy transition that can be achieved. According to Bridge, location is defined by the physical places where energy can be collected and where it is needed. Territoriality is defined by how energy production network is organised geographically to generate and capture value. Scaling is how material and area size affects development of energy, where different size of energy development affects the price and economic of energy.

In this chapter, other energy geography indicators such as grid complexity as shown in Table 4-19 or population density as shown in Table 4-20 should be noted its importance in ensuring the implementation of energy policy.

Table 4-19 Island's energy grid complexity

Islands	Transmission Line (km)				Distribution Line (km)			Capacity MW	Elect.
	275kV	150kV	70kV	Total	MV	LV	Total		
Sumatra	1,028	8,597	332	9,957	79,472	88,024	167,496	6,357	80%
Jawa	5,052	12,977	3,474	21,503	143,941	237,297	381,238	30,369	85%
Kalimantan	0	3,028	528	3,556	24,384	23,382	47,766	1,632	80%
Bali	0	0	0	0	8,468	8,362	16,830	483	65%
Sulawesi	482	2,988	528	3,998	24,925	27,284	52,209	1,731	71%
Maluku	0	0	0	0	4,813	2,718	7,531	286	70%
Papua	0	0	0	0	2,718	3,637	6,355	241	65%

Table 4-20 Island's population density

Islands	Population		GDP		Islands	Area			
	Total	Growth	Growth	Cap.		Total	Plant.	Forest	Paddy
Sumatra	54.6	1.90%	2.30%	$ 4,100	5,277	443,066	70,329	53,579	22,183
Jawa	148.2	1.20%	9.60%	$ 4,600	1,086	138,794	334	13,891	32,484
Kalimantan	15.6	2.10%	2.30%	$ 5,800	1,061	594,664	37,143	108,487	10,482
Bali	15.6	1.40%	0.80%	$ 2,200	2,141	73,070	167	6,946	16,242
Sulawesi	18.2	1.60%	0.70%	$ 2,500	2,500	180,681	3,679	11,535	10,163
Papua	7.8	2.10%	0.50%	$ 2,400	5,439	151,691	1,119	80,529	765

Territoriality analysis is performed to understand the region's complexity which indicated by electricity grid complexity, transmission and distribution line length, electricity capacity and electrification ratio. This explained by analyze the length of transmission and distribution line relative to the size of region. Scaling analysis is performed to understand the role of material and area size in the energy development, in this case is population density. Java is the region that has the highest population and GDP growth compare with another region. Scaling is related with the development of biofuel energy, for example the maximum potential energy will be affected by the land availability. Therefore, it also must be noted that these geographical factors are still a significant factor that might affect the opportunities for, and barriers to, energy development in Indonesia.

4.7. Conclusion

As of 2010, Indonesia has Total Primary Energy Supply (TPES) of 210 Million Tonnes of Oil Equivalent (Mtoe) and expected to have 400 Mtoe by 2030. The technical potential of renewable energy sources in Indonesia is 550 Mtoe. Five sources of energy in the energy mix as capacity targets which are oil, coal, gas, renewable and biomass; and five sources of renewable energies which are geothermal, hydropower, biodiesel, wind and solar PV.

In the analysis, six regions (Sumatra, Jawa, Bali, Kalimantan, Sulawesi and Papua) are selected, across four sectors which are transportation, residential, electricity and industry. The examination is contrasting the current scenario development study that mainly focusing on the national or local level which lack of analysis in the geographical features. It can be concluded that maximum effective emission reduction can be achieved by considering the analysis of geographical features and using 100% renewable energy source. In this chapter total six scenarios are examined as Table 4-21 below.

Table 4-21 Proposed scenario for 2030

Scenario	Energy (Mix)					Renewable (Mix)				
	Oil	**Coal**	**Gas**	**RE**	**BM**	**Geo**	**Win**	**Bio.**	**Hyd**	**Sol.**
Baseline (BASE)	34%	15%	18%	8%	24%	90%	0%	0%	10%	0%
Planned Renewable (RENGOV)	38%	17%	20%	21%	4%	40%	7%	35%	10%	8%
Planned Clean (CLEANGOV)	40%	18%	33%	5%	4%	40%	7%	35%	10%	8%
Adjusted Renewable (RENEW)	33%	16%	24%	14%	13%	40%	7%	35%	10%	8%
Adjusted Clean (CLEAN)	37%	18%	25%	7%	13%	40%	7%	35%	10%	8%
Max Reduction (MFRE)	0%	0%	0%	100%	0%	5%	2%	5%	11%	77%

The developed scenarios have a simulation length of 20 years, 2010 used as base year and ending in 2030. The renewable energy scenario will simulate what happens if Indonesia focuses on the increased development of renewable energy whereas in the clean energy scenario, fossil fuel energy such as gas and oil energy is dominated the market. It can be concluded that energy scenarios can be constructed by examining the economic, political, and social factors as drivers, further a quantitative adjustment is made to estimate the future share of energy mix in Indonesia.

Overall, it can be concluded that this method helps to challenge the assumptions on the capacity target such as energy mix that and helps to evaluate the choices and options available. The combination of interview and geographical analysis is proposed for scenario development in order to: 1) improve the understanding of the future complexity; 2) challenge the assumptions of capacity target, and 3) improve the quality of the decisions made by adding geographical analysis.

Finally, based on the method described in this chapter, four scenarios have been developed to describe the future state of Indonesia’s energy system. The proposed method is developed with a focus on the specific characteristics of Indonesia. Further, the impact of energy scenario being chosen will be examined in the Chapter 5 Impact assessment. The Chapter 5 will analysis the health impact of each energy scenarios. The focus on the impact analysis is to understand the maximum benefit that can be achieved

Appendix 1 Scenario data

The summary of detail emission scenario including each sector described in Figure 4-10. The detail calculation made in the Microsoft Excel

	ENERGY (MTOE)						ENERGY (MIX)						RENEWABLE (MTOE)						RENEWABLE (MIX)					
SCENARIO	Oil	Coal	Gas	RE	BM	Total	Oil	Coal	Gas	RE	BM	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total
TPES 2010 base year	71.7	31.8	38.8	17.5	50.5	210.3	34%	15%	18%	8%	24%	100%	15.8	-	-	1.8	-	17.5	90%	0%	0%	10%	0%	100%
1.Baseline (BASE) 2030	136.4	60.5	73.8	33.3	96.1	400.0	34%	15%	18%	8%	24%	100%	30.0	-	-	3.3	-	33.3	90%	0%	0%	10%	0%	100%
2.Planned Renewable (RENE) 2030	152.0	68.0	80.0	84.0	16.0	400.0	38%	17%	20%	21%	4%	100%	33.6	5.9	29.4	8.4	6.7	84.0	40%	7%	35%	10%	8%	100%
3.Planned Clean Energy (CENE) 2030	160.0	71.1	133.3	20.0	16.0	400.4	40%	18%	33%	5%	4%	100%	8.0	1.4	7.0	2.0	1.6	20.0	40%	7%	35%	10%	8%	100%
4.Realistic Renewable (RERE) 2030	133.2	65.4	96.8	54.2	50.5	400.0	33%	16%	24%	14%	13%	100%	21.7	3.8	19.0	5.4	4.3	54.2	40%	7%	35%	10%	8%	100%
5.Realistic Clean Energy (RECE) 2030	148.7	72.9	100.5	27.4	50.5	400.0	37%	18%	25%	7%	13%	100%	11.0	1.9	9.6	2.7	2.2	27.4	40%	7%	35%	10%	8%	100%
6.Maximum Reduction (MFR 2030	-	-	-	400.0	-	400.0	0%	0%	0%	100%	0%	100%	21.8	6.0	19.2	44.0	309.0	400.0	5%	2%	5%	11%	77%	100%

	RENEWABLE (MTOE)						RENEWABLE (MIX)						RENEWABLE POTENTIAL (MTOE)						RENEWABLE POTENTIAL (MIX)					
SCENARIO	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total
6.Maximum Reduction (MFR) 2030	21.8	6.0	19.2	44.0	309.0	400.0	5%	2%	5%	11%	77%	100%	30.0	8.3	26.4	60.5	425.5	550.7	5%	2%	5%	11%	77%	100%
i.Sumatra	9.3	0.6	8.6	8.6	75.5	102.5	9%	1%	8%	8%	74%	100%	12.7	0.8	11.7	11.7	103.1	140.0	9%	1%	8%	8%	74%	100%
ii.Jawa	37.7	12.8	30.3	14.2	127.5	222.5	17%	6%	14%	6%	57%	100%	8.6	2.9	6.9	3.2	29.1	50.8	17%	6%	14%	6%	57%	100%
iii.Kalimantan	-	-	1.1	4.7	32.3	38.0	0%	0%	3%	12%	85%	100%	0.0	0.0	3.8	16.2	112.0	132.1	0%	0%	3%	12%	85%	100%
iv.Bali	0.8	0.4	0.3	1.2	7.2	9.9	8%	4%	3%	12%	73%	100%	2.8	1.5	1.0	4.1	25.1	34.4	8%	4%	3%	12%	73%	100%
v.Sulawesi	1.6	1.0	0.7	2.8	17.3	23.4	7%	4%	3%	12%	74%	100%	4.6	2.9	2.0	8.1	50.2	67.8	7%	4%	3%	12%	74%	100%
vi.Papua	0.0	0.0	0.0	0.5	3.0	3.6	1%	0%	1%	14%	84%	100%	1.3	0.2	1.0	17.1	105.9	125.6	1%	0%	1%	14%	84%	100%

	ENERGY (MTOE)						ENERGY (MIX)						RENEWABLE (MTOE)						RENEWABLE (MIX)					
SCENARIO	Oil	Coal	Gas	RE	BM	Total	Oil	Coal	Gas	RE	BM	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total
1.Baseline (BASE) 2030	136.4	60.5	73.8	33.3	96.1	400.0	34%	15%	18%	8%	24%	100%	29.96	-	-	3.33	-	33.29	90%	0%	0%	10%	0%	100%
i.Electricity	13.7	32.4	15.8	10.1	-	72.0	19%	45%	22%	14%	0%	100%	9.07	-	-	1.01	-	10.08	90%	0%	0%	10%	0%	100%
ii.Industry	16.5	25.4	24.8	9.3	-	76.0	22%	33%	33%	12%	0%	100%	8.38	-	-	0.93	-	9.31	90%	0%	0%	10%	0%	100%
iii.Transport	64.0	-	-	-	-	64.0	100%	0%	0%	0%	0%	100%	-	-	-	-	-	-	0%	0%	0%	0%	0%	0%
iv.Residential	7.9	-	-	-	96.1	104.0	8%	0%	0%	0%	92%	100%	-	-	-	-	-	-	0%	0%	0%	0%	0%	0%
v.Other	18.3	28.1	27.4	10.3	-	84.0	22%	33%	33%	12%	0%	100%	9.27	-	-	1.03	-	10.30	90%	0%	0%	10%	0%	100%

	ENERGY (MTOE)						ENERGY (MIX)						RENEWABLE (MTOE)						RENEWABLE (MIX)					
SCENARIO	Oil	Coal	Gas	RE	BM	Total	Oil	Coal	Gas	RE	BM	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total	Geoth	Wind	Biofuel	Hydro	Solar	Total
2.Planned Renewable (RENE) 2030	152.0	68.0	80.0	84.0	16.0	400.0	38%	17%	20%	21%	4%	100%	33.60	5.9	29.4	8.40	6.7	84.00	40%	7%	35%	10%	8%	100%
i.Electricity	13.6	24.5	15.6	18.0	-	72.0	19%	34%	22%	25%	0%	100%	11.16	0.7	3.6	1.62	0.9	18.00	62%	4%	20%	9%	5%	100%
ii.Industry	16.5	16.0	24.8	19.0	-	76.0	22%	21%	33%	25%	0%	100%	9.50	0.6	6.3	1.90	0.8	19.00	50%	3%	33%	10%	4%	100%
iii.Transport	48.0	-	-	16.0	-	64.0	75%	0%	0%	25%	0%	100%	-	-	16.0	-	-	16.00	0%	0%	100%	0%	0%	100%
iv.Residential	7.9	-	-	80.1	16.0	104.0	8%	0%	0%	77%	15%	100%	7.21	1.6	64.1	4.80	2.4	80.08	9%	2%	80%	6%	3%	0%
v.Other	18.3	17.6	27.4	21.0	-	84.0	22%	21%	33%	25%	0%	100%	10.50	0.6	6.9	2.10	0.8	21.00	50%	3%	33%	10%	4%	100%

Figure 4-10 Detail emission scenario

Appendix 2 Interview data

Table 4-22 List interview 2016

No	Name	Institution	Description
1	Interviewee 01	PT Pertamina	Indonesia national oil company
2	Interviewee 02	PT Pertamina	Indonesia national oil company
3	Interviewee 03	Chevron	
4	Interviewee 04	Petronas	Malaysian national oil company
5	Interviewee 05	Rekind	Indonesia state own company
6	Interviewee 06	Angkasa Pura	Indonesia state own company
7	Interviewee 07	Standard Chartered Bank	
8	Interviewee 08	Pricewaterhouse Coopers	
9	Interviewee 09	Ernst & Young	
10	Interviewee 10	Consultant	
11	Interviewee 11	Consultant	
12	Interviewee 12	USAID	
13	Interviewee 13	ASEAN Energy	
14	Interviewee 14	ASEAN Energy	
15	Interviewee 15	Indonesian Petroleum Association	
16	Interviewee 16	World Health Organization	
17	Interviewee 17	University of Indonesia	
18	Interviewee 18	University of Indonesia	
19	Interviewee 19	Petra Christian University	
20	Interviewee 20	Pembangunan Jaya University	
21	Interviewee 21	Gadjah Mada University	
22	Interviewee 22	Ministry of Energy	
23	Interviewee 23	Ministry of Energy	
24	Interviewee 24	Ministry of Finance	

25	Interviewee 25	Ministry of Finance
26	Interviewee 26	Ministry of Finance
27	Interviewee 27	Ministry of Finance
28	Interviewee 28	Government - Central Bank
29	Interviewee 29	Government - Audit Board
30	Interviewee 30	Government - Public Service
31	Interviewee 31	Government - Public Service
32	Interviewee 32	Ministry of Health
33	Interviewee 33	Ministry of Health
34	Interviewee 34	Government - Public Service

Table 4-23 List interview 2017

No	Name	Institution	Description
1	Interviewee 01	Pertamina	Indonesian national oil company
2	Interviewee 02	Chevron	American Multinational energy company
3	Interviewee 03	General Electric	American Energy Company
4	Interviewee 04	Petronas	Malaysian national oil company
5	Interviewee 05	Pricewaterhouse Coopers	Pricewaterhouse Coopers
6	Interviewee 06	Pertamina	Indonesia national oil company
7	Interviewee 07	Siemens Indonesia	Siemens Indonesia
8	Interviewee 08	Halliburton	Halliburton
9	Interviewee 09	Angkasa Pura	Indonesia State Owned Company
10	Interviewee 10	SKK Migas	Indonesia Ministry of Energy
11	Interviewee 11	SKK Migas	Indonesia Ministry of Energy
12	Interviewee 12	Government - Central Bank	Government - Central Bank
13	Interviewee 13	Government - Public Service	Government - Public Service
14	Interviewee 14	Ministry of Health	Ministry of Health
15	Interviewee 15	Government - Public Service	Government - Public Service

Informed Consent Form

Form Number: Date : Location :	

My name is Anjar Priandoyo, PhD Environment Student from University of York, UK. I am doing research on a project entitled "Energy and Environment in Indonesia". My supervisor, Dr Lisa Emberson is directing the project and can be contacted at:

Department of Environment
University of York
Heslington, York, YO10 5DD

Thank you for agreeing to take part in this project. Before we start, I would like to emphasise that:

- Your participation is entirely voluntary
- You are free to refuse to answer any question
- You are free to withdraw at any time

The interview will be tape-recorded, but the data will be kept strictly confidential and will be available only to members of the research team. Excerpts from the results may be made part of the final research report, but under no circumstances will your name or any identifying characteristics be included in the report.

All information provided is considered completely confidential. Name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used.

Please sign this form to show that I have read the contents to you.

Name : Saifuddin Suaib Signature :	Name : S Signature :
Additional Information	

Informed Consent Form

Form Number: Date : Location :	

My name is Anjar Priandoyo, PhD Environment Student from University of York, UK. I am doing research on a project entitled "Energy and Environment in Indonesia". My supervisor, Dr Lisa Emberson is directing the project and can be contacted at:

Department of Environment
University of York
Heslington. York, YO10 5DD

Thank you for agreeing to take part in this project. Before we start, I would like to emphasise that:

- Your participation is entirely voluntary
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All information provided is considered completely confidential. Name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used.

Please sign this form to show that I have read the contents to you.

Name : IRFAN AKBAR Signature : IRFAN AKBAR	Name : Signature :
Additional Information Phone number: 0811903637.	

Information Sheet for participants

This research will involve developing and applying an existing Long Term Energy Planning Tool (LEAP) for Indonesia. The tool allows scenarios for the future energy mix to be investigated in relation to supplying energy demand whilst meeting certain environmental targets. The focus will be in low carbon energy supply and reduced emissions of short lived climate pollutants (air pollutants that also influence climate (as well as damaging human health and agriculture). The research will develop these scenarios on consideration of feasibility (in relation to both technological solutions and societal behaviour) and the likelihood of policy implementation in Indonesia

What is the research objective?
The objectives of this research are to define current energy environment system and energy transition factors, to develop impact analysis of future energy scenario, and to evaluate energy scenario. This objective will be translated into three questions that would be themes in this interview.

- Main Question: How is long term energy planning towards optimal energy mix and reduced emissions
- Energy Transition: How do regime actors view Indonesia's future energy mix? What is the enablers and obstacle of energy transition in Indonesia? How energy and environment related?
- Impact Analysis: What is the impact of energy development and air pollution for human health and environment?
- Scenario Analysis: What is the optimal energy scenario for Indonesia?

Why have I been invited?
There are 22 participant selected to represent the government, non-government and private sector in Indonesia. Recruitment is conducted via email and phone. The participants are not received any payments regarding this activities.

What will happen to me if I take part?
There will be question related the energy transition in Indonesia mainly on area of energy transition, impact analysis and scenario analysis. The duration is around 45 minutes.

Will my taking part in the study be kept confidential?
All information in the interview is treated as confidential and store in secured place, align with Information Technology Law of Indonesia no 2008.

What will happen to the results of the research study?
The results will be made available to participants. Participants will not be identified in any report/publication unless they have given their consent.

Who is organising or sponsoring the research?
The organizer of this research is from University of York and the funding is from Government of Indonesia.

Notes:

Chapter 5 Impact assessment of atmospheric emissions

This chapter is an impact assessment analysis of the emission reduction energy scenarios for Indonesia. The objective of this chapter is to determine the wider environmental impacts resulting from the development of energy transition scenarios that have been developed to reduce air pollution and GHG emissions associated with energy supply and use and to what extent renewable energy or clean energy sources can help to overcome these impacts.

The tool that used in this chapter is Long-range Energy Alternatives Planning system - Integrated Benefits Calculator (LEAP-IBC). In this section, the three scenarios developed in Chapter 4 to mitigate emissions are applied within the LEAP-IBC tool to estimate emissions and consequent atmospheric concentrations of air pollution and GHG. An assessment of these atmospheric concentrations impact on human health and influence on global temperature from 2010 to 2030. This provides an assessment of the influence of such an energy transition in Indonesia.

5.1. Introduction

Air pollutant such as particulate matter cause damage to human health respiratory infections and inflammations, cardiovascular dysfunctions, and cancer. Study indicated that particles of smaller size reach the lower respiratory tract and have greater potential for causing the lungs and heart disease (Ghorani-Azam et al., 2016). The recent Global Burden Disease (GBD) project that was coordinated by the Institute for Health Metrics and Evaluation (IHME) (Cohen et al., 2017), carried out a study to compare the burden of disease from various risk factors, including air pollution. To assess the influence of air pollution on human health, GBD developed integrated exposure–response (IER) function that estimate risk from air pollution over the entire range of exposure.

In Indonesia, according to GBD, air pollution is one of the five risk factors that cause most of the premature mortality which are high blood pressure, dietary risks, tobacco and high fasting plasma glucose (blood sugar level) as shown in Figure 5-1 (GBD, 2015). Study also indicated that Indonesia also one of the most populated and polluted region in the world especially in term of particulate matter pollution (Both et al., 2013). Moreover, the peer-reviewed studies that measured exposure of air pollution in Indonesia is relatively few compare with other developing country (Both et al., 2013).

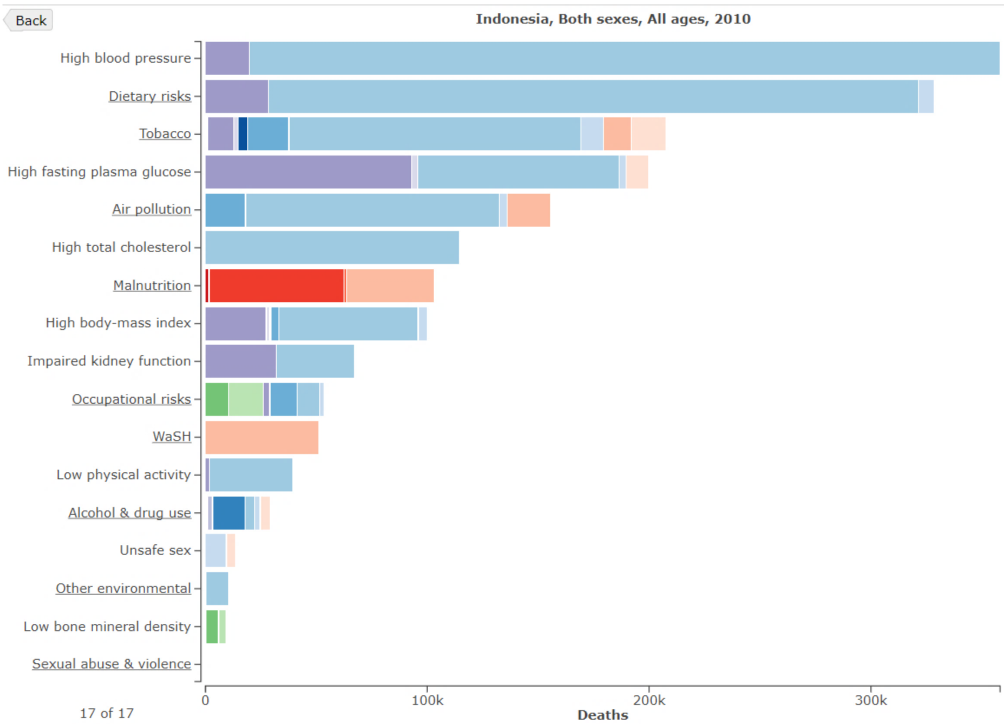

Figure 5-1 Leading risk factors for premature death in Indonesia (GBD, 2015)

Exposure to air pollution is linked to an increased risk of death from chronic cardiovascular and respiratory disease. It was estimated that air pollution in Indonesia caused the premature death of 155,609 people in 2010, where 97,783 caused by household air pollution and 70,700 ambient air pollutions. However, in 2016, this trend is changing where ambient air pollution overtaken the most caused of death by 79,739 and followed by household air pollution by 60,835 as shown in Figure 5-2.

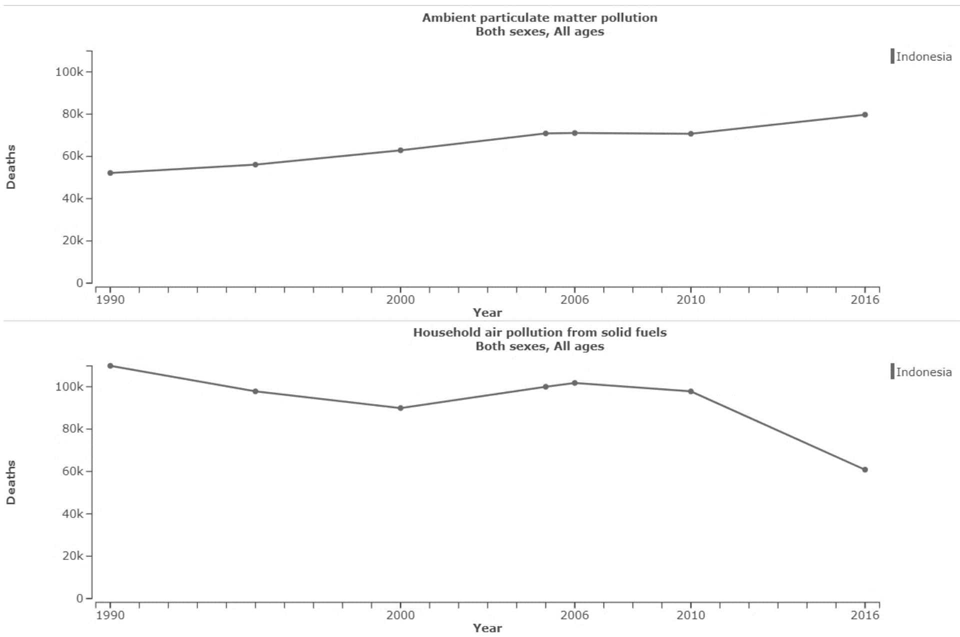

Figure 5-2 Household vs ambient air pollution (GBD, 2015)

The decreased of household air pollution can be explained by the introduction of LPG as residential fuel cooking starting in 2007 which involve 58 million household (Permadi et al., 2017). In Indonesia, the use of biomass in the residential sector is a key emission sources which mainly responsible for indoor air pollution. The focus in this thesis is ambient air pollution which the trend is showing an increase.

Impact assessment shows that air emission has multiple benefit in term of human health or climate. Therefore, it is important to have integrated mitigation policies for all related air emission pollutant such as air pollution and GHG to get benefits for health as well for climate. This integrated mitigation policies would be helping to solve the thinking in silos problem and conflicting policies.

As in other developing countries, air pollution in Indonesia is a major environmental health problem. According to one study $PM_{2.5}$ concentration in five cities in Indonesia in 2011 ranged from 7.7 - 18.4 $\mu g/m^3$ (Santoso et al, 2013) which is higher than WHO recommendation of 10 $\mu g/m^3$ annual mean (Krzyzanowski and Cohen, 2008). Santoso perform analysis in Bandung, Jakarta, Palangka Raya, Serpong and Yogyakarta where the average $PM_{2.5}$ for each city is 18.35, 16.50, 7.74, 16.68, and 8.78 $\mu g/m^3$

In Indonesia, studies of air pollution have been performed in various place such as in Jakarta (Santoso et al., 2011), Central Java (Budisatria et al., 2007), East Java (Jennerjahn et al., 2013), South Sulawesi (Rashid et al., 2014) and South Sumatera (Colenbrander et al., 2015). Therefore, based on the studies above it is important to explore the influence of different energy transitions scenarios on human health.

5.1.1. Greenhouse gases emissions and influence in Indonesia

Greenhouse gases (GHG) consist of various gasses such as CO_2, CH_4, and N_2O. Each of these gasses has different lifetime in atmosphere from 50-200 year for CO_2, 12 years for CH_4 and 121 years for N_2O (IPCC, 2006). Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2) (US-EPA, 2018). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period that used in this analysis 100 years.

Reduction of ozone precursors is important to ensure the reduction of tropospheric ozone concentration. Ozone precursors can be defined as a chemical compound, such as carbon monoxide, methane, NMVOCs and nitrogen oxide which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the tropospheric ozone concentration

(EEA, 2015). Transport sector is the biggest sector that produce ozone precursors such as from nitrogen oxide and NMVOCs.

Indonesia is identified as the sixth largest GHGs emitter, accounting for 4.5% global emissions, with Indonesia's energy sector making up to 25% of total emissions (World Bank, 2007). These GHGs emissions come from energy use in power generation at 42%, transport at 25%, industry at 21% and the rest from the residential sector (IEA, 2015). The trend in the long run show an increase of GHGs due to various factor from economic growth to urbanization (Resosudarmo et al., 2009). Therefore, based on this a mitigation strategy should be developed in order to reduce GHGs in Indonesia.

5.1.2. Impact assessment

Impact assessments are a scientific evaluation of potential risk resulting from the emission, and consequent concertation, of atmospheric emissions of pollutants. Assessments allow us to understand the influence of concentrations and exposure on a variety of receptors and include effects on human health or temperature response to climate forcing. The following are required in an impact assessment: 1) a means of estimating the pollutant concentration from emissions estimates; 2) a means of estimating the resulting exposure of different receptors from a pollutant concentration (e.g. the population exposed to a given concentration over a particular time averaging period); 3) a means of estimating the effect of the exposure e.g. on human health (WHO, 2016). Impact assessments are intended to inform policy through giving an understanding of how emissions translate into impacts so that effective emission reduction options can be explored and implemented. Impact assessment is an integral part within society and environment interaction as described by DSPIR framework that explained in Chapter 3.

An impact assessment takes a cost-benefit type approach to provide policy makers with comprehensive information on possible effects caused by pollution, from which an assessment of the benefits of control of emissions can be made (Pubule et al., 2012). In air pollution impact assessments, the monitoring station data is one of the approaches that used as baseline data that later analyze using air emission modelling to understand future concentration.

Impact assessment requires information about air pollution concentration levels, the relationship between concentrations and health outcomes, and the characteristics of the populations exposed, including their baseline health status, age, and location (Anenberg et al., 2016). The interaction of pollutant concentration and health impact shown in Figure 5-3 below.

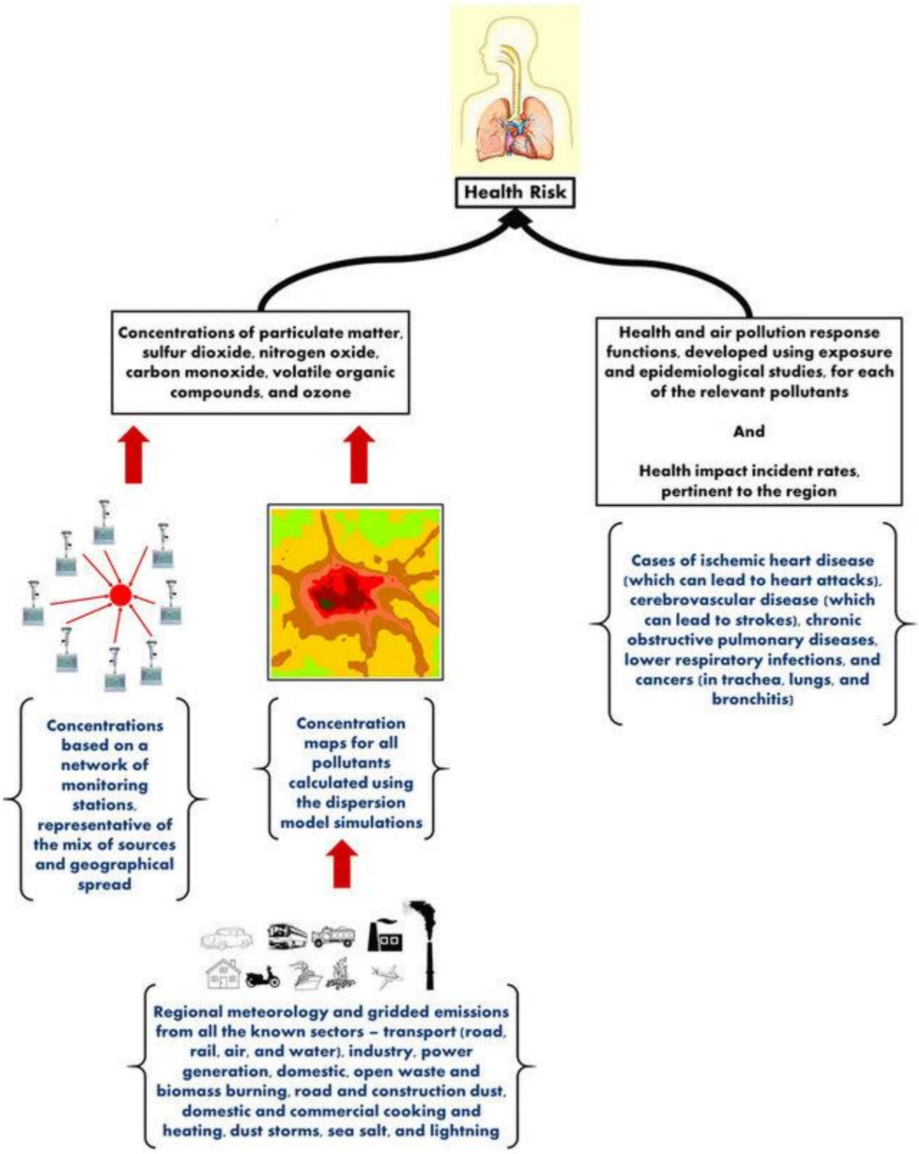

Figure 5-3 Interaction pollutant concentration and health impact (Anenberg 2016)

In health impact assessment, epidemiological studies which study relationship between pollutant concentration and health outcome is used. The relationship between pollutant and health outcome is measured in term of Concentration Response Function (CRF). The relationship between pollutant and health population is measured in term of Relative Risk (RR). RR is expressed as the proportional increase in the assessed health outcome associated with a given increase in pollutant concentrations in µg per m^3 or parts per billion (ppb). RR describes risk in a defined population not individual risk. The result of health impact assessment is usually reported in terms of number of the attributable deaths. This thesis used integrated exposure–response (IER) which estimate risk from air pollution over the entire range of exposure.

In global climate temperature impact assessment, an impact can be estimated using equilibrium sensitivity or transient climate sensitivity. In equilibrium sensitivity, the temperature change realized after allowing the climate system to equilibrate with a higher value of CO_2. Transient climate sensitivity is quantified by raising the CO_2 in a model at the rate of 1% per year and examining the response at the time when CO_2 concentration has doubled. Equilibrium sensitivities in global climate models typically range from 2 to more than 4 °C, while the transient climate responses are smaller, in range of 1.0-2.5 °C (GFDL, 2016).

Transient climate model can be estimated using Forward Model (source oriented) or using Adjoint Model (receptor-oriented). Forward model estimated sensitivity of all model concentrations to one model source, while adjoint model estimated sensitivity of model concentration in specific location to many model sources. Transient climate calculated for a scenario in which emissions of aerosols, aerosol precursors, and GHGs are linearly eliminated over a 20-y horizon.

5.2. Methodology

The methodology used in this scenario analysis is integrated energy supply and demand modelling and uses the LEAP to develop analyses of future energy consumption and related emission (Heaps, 2012). LEAP is an energy policy analysis and climate change mitigation assessment tool widely-used, particularly by developing countries, for energy scenario analysis. The LEAP version that used in this chapter is LEAP-IBC which a new application of LEAP that incorporates GEOS-Chem adjoint coefficient and GAINS default emissions.

5.2.1. LEAP-IBC tools

The LEAP-IBC tool is used for benefit calculation that allow for estimates of emissions produced in LEAP to be used to quantify impacts of air pollutants on human health and the impacts of both air pollutants and greenhouse gases on climate (as temperature change) (Heaps, 2018). IBC tool process flow with the output of analysis shown in Figure 5-4. The LEAP-IBC tool following standardised methods described in the GAP Forum emission inventory manual (Vallack and Rypdal 2019)

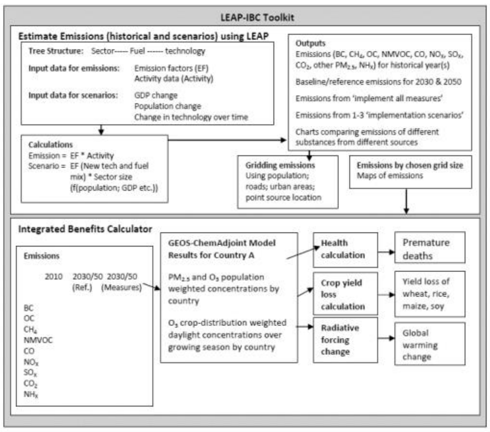

Figure 5-4 LEAP-IBC tool process flow (Vallack, 2017)

For all scenarios the base year used is 2010 and projections end in 2030. BASE is the baseline scenario where there is no change in the energy system between 2010 and 2030. The mitigation scenarios used in this section are based on the analysis in previous Chapter 4 Scenario Development and Chapter 3 Emission Inventory, as shown in Table 5-1. In total there are three mitigation scenarios simulated to understand the impacts of energy transition in Indonesia which are Clean fossil fuel energy scenario (CLEAN), Renewable energy scenario (RENEW) and Maximum feasible renewable energy scenario (MFRE).

GEOS-Chem is a global 3-D chemical transport model (CTM) for atmospheric composition driven by meteorological input from the Goddard Earth Observing System (GEOS) of the NASA Global Modelling and Assimilation Office (Henze et al., 2007). Chemical transport models (CTM) is a model that used to understand the relationship between emission sources and their impacts are atmospheric models that attempt to simulate all of these chemical, physical, and radiative aerosol processes. CTM treat these chemical and physical processes in the atmosphere by solving mass balance equations for various species in each grid cell (Lacey et al., 2017).

GEOS-Chem adjoint coefficients are used to quantify the sensitivity of $PM_{2.5}$ and ozone concentrations in the target country to NO_x, SO_2, NH_3, BC, VOCs, CO, OC, and CH_4 emissions from every grid square across the world. These sensitivities are calculated for a base set of emissions for the year 2010. The coefficients are applied in IBC to look at changes in $PM_{2.5}$ concentrations in the target country that result from changes in emissions in the target country, and across the world.

5.2.2. Methodology for air pollution impact assessment

Human health impacts are estimated by combining the modelled grid-cell aerosol mass concentrations with satellite data and rescaling to the match the annual average $PM_{2.5}$ concentrations from this dataset, along with redistribution from the 2° by 2.5° resolution to the 0.1° by 0.1° resolution that is appropriate for estimating human exposure. These exposure estimates are then combined with IER functions to estimate grid-scale premature deaths from exposure to Ambient Air Pollution (AAP). For estimation of aerosol radiative forcing, the LIDORT radiative transfer model is used to estimate the grid cell contributions to radiative flux for a baseline pre-industrial state and perturbed case, either present day or future atmospheric condition (Lacey et al., 2017).

The estimate of annual average population-weighted $PM_{2.5}$ concentration in Indonesia used in LEAP-IBC for 2010 (12.1μg/m^3) is derived from satellite data (van Donkelaar et al., 2016). This $PM_{2.5}$ concentration in Indonesia is above the WHO recommendation (WHO, 2017) of 10 μg/m^3.

Health impact calculation is made for $PM_{2.5}$ and ozone. For $PM_{2.5}$ associated mortality, the Burnett et al. (2014) method using Integrated Exposure Response (IER) functions that quantify the Relative Risk (RR) for mortality for $PM_{2.5}$ exposures up to very high levels (10,000 μg m^{-3}) were applied as shown in equation below (Burnett et al., 2014) covering all ages.

RRIER = 1 + α (1 – exp [-γ (z-zcf) δ]) (Equation 1)

- zcf is the $PM_{2.5}$ low concentration cut-off. For the IER functions, the low concentration cut-off was set as a uniform distribution between 5.8 and 8.8 μg m^{-3},
- z is the $PM_{2.5}$ exposure, and
- α, γ, and δ are parameters derived by fitting the model to RRs across a large $PM_{2.5}$ concentration range.

5.2.3. Methodology for GHG impact assessment

This section describe the methodology for GHG impact assesment. This to estimates of effect on global mean temperature. Climate temperature impact calculation that used in this research is adjoint model calculation. Adjoint model calculations are used to calculate the sensitivities of regional radiative forcing (RF) in four different latitude bands with respect to grid-scale emissions of aerosols and aerosol precursors (Lacey and Henze, 2015). Regional RF values are combined with absolute regional temperature potentials to estimate surface temperature response. These GHG RF impacts are then combined with the aerosol RF to estimate the total RF as a transient function. This net RF is multiplied by the transient global mean sensitivities and integrated for all prior years to estimate the temperature response of an emissions perturbation as a function of time (Lacey et al., 2017). The impact calculation of estimate radiative forcing and estimate of global or regional mean temperature response performed within LEAP IBC.

5.2.4. Estimates of biodiesel production emission

In this chapter, Land use change (LUC) rate is calculated based on the simulation of total biodiesel consumption in 2030. The land requirement is calculated with the following equation:

$$\boldsymbol{L = B / Y} \qquad \text{(Equation 2)}$$

L = Land requirement (Ha)

B = Total biodiesel consumption (tonnes of oil equivalent (TOE))

W = Biodiesel yield (TOE/ha/yr)

In Indonesia, as of 2010 total consumption of diesel is 60 Mtoe, around 85% of this diesel consumption or 51 Mtoe is for transportation sector. Diesel consumption in transportation sector is estimated to reach 72 Mtoe by 2030. Biodiesel consumption is estimated to reach 21 Mtoe by 2030 or around 30% of diesel fuel based on Indonesia energy policy. Biodiesel consumption is from domestic production. Analysis in this section is based on biodiesel in transportation sector.

Biodiesel yield is estimated to 4.2 TOE per hectare per year. Therefore, land requirement needed to achieve this biodiesel target is around 5 million ha, which translates into an average increase of 0.25 million ha per year of land change by using forest fire over 20 years. For the LEAP-IBC modelling, forest fire that is not related to biodiesel was estimated by assuming the average incidence of forest fire before 2010 which was around 1.5 million ha per year.

Impacts of both biodiesel production and consumption is measured in this study in terms of human premature mortality linked to ambient air pollution as calculated using LEAP-IBC. Biodiesel consumption emission is calculated using simple method as the following equation:

$$\boldsymbol{E} = \boldsymbol{A} \times \boldsymbol{EF} \qquad \text{(Equation 3)}$$

E = Annual emission of a given pollutant A = Activity rate (fuel consumption)
EF = Default emission factor of a given pollutant

Biodiesel production emission is calculated based on biodiesel land use change rate. Estimation of emission (E) from biodiesel production used the following equation.

$$\boldsymbol{E} = \boldsymbol{P} \times \boldsymbol{B} \times \boldsymbol{EF} \qquad \text{(Equation 4)}$$

P= Annual area burnt
B= Biomass consumption

Forest data used in this assessment is based on a study by Harahap (2017). The forest can be classified by vegetation as shown in Table 5-1 and by type of permit as shown in Table 5-2. Type of vegetation indicate distribution of vegetation in the forest.

Table 5-1 Forest classification by vegetation

Classification by vegetation	**Mha**
Primary dry forest	38.00
Secondary dry forest	38.30
Swamp forest	11.50
Mangrove forest	2.90
Plantation forest	4.70
Shrub/bush/swamp (peatland)	23.00
Dry land farming	37.30
Rice field	7.60
Area without forest cover	24.28
Total	187.58

Classification by type of permit indicate how big the forest that available for exploitation, can be converted or protected by government.

Table 5-2 Forest classification by type

Classification by type	Mha
Forest conservation	21.9
Forest protected	29.6
Forest production – limited	26.8
Forest production – permanent	29.2
Forest production – convertible	13.1
Paddy field (sawah)	8.09
Plantation	28.96
Non-forest & plantation (residency, road, office, industry)	29.93
Total	187.58

The forest and plantation data in Indonesia vary from one agency to another agency. However in this analysis forest fire data are taken from various sources: for 2003-2015, data is based from Global Fire Emission Database (GFED), 2016 data is based from Ministry of Environment data, 1982-1997 data is from (Page et al., 2002). Palm oil size data from 1982-2016 is taken from FAOSTAT. Area of palm oil plantation used to produce biodiesel is from Ministry of Agriculture while biodiesel consumption data is taken from Ministry of Energy and Mineral (MOEMR, 2017). Summary of this data shown in Table 5-3.

Table 5-3 Forest fire, palm oil and biodiesel land size

Year	Forest Fire Size (ha/yr)	Palm Oil plantation cumulative area (ha)	Area of palm oil plantation used to produce biodiesel ha)	Biodiesel (ktoe)
1982	5,000,000	239,700	-	-
1983	3,200,000	255,300	-	-
1991	500,000	772,245	-	-
1994	5,100,000	1,045,000	-	-
1997	9,750,000	1,622,503	-	-
2003	1,054,700	3,040,000	-	-
2004	2,469,600	3,320,000	-	-
2005	959,000	3,690,000	-	-
2006	3,605,400	4,110,000	-	-
2007	795,100	4,560,000	-	-
2008	700,800	4,980,000	-	-
2009	2,080,800	5,370,000	-	-
2010	383,700	5,780,000	680,000	208
2011	1,119,500	6,170,000	938,000	1,548
2012	1,103,200	6,650,000	2,090,000	1,897
2013	841,200	7,080,000	3,269,000	2,396
2014	2,213,700	8,150,000	3,989,000	2,834
2015	3,578,900	8,630,000	2,681,000	1,008

Note: ktoe = kilotonnes of oil equivalent

Historical vehicle data shown in Table 5-4 below. This data will be used to estimate the future of vehicle data in Indonesia.

Table 5-4 Historical vehicle data

Year	Passenger Car	Bus	Heavy Duties	Motorcycle
1986	1,063,959	256,574	882,331	5,118,907
1987	1,170,103	303,378	953,694	5,554,305
1988	1,073,106	385,731	892,651	5,419,531
1989	1,182,253	434,903	952,391	5,722,291
1990	1,313,210	468,550	1,024,296	6,082,966
1991	1,494,607	504,720	1,087,940	6,494,871
1992	1,590,750	539,943	1,126,262	6,941,000
1993	1,700,454	568,490	1,160,539	7,355,114
1994	1,890,340	651,608	1,251,986	8,134,903
1995	2,107,299	688,525	1,336,177	9,076,831
1996	2,409,088	595,419	1,434,783	10,090,805
1997	2,639,523	611,402	1,548,397	11,735,797
1998	2,769,375	626,680	1,586,721	12,628,991
1999	2,897,803	644,667	1,628,531	13,053,148
2000	3,038,913	666,280	1,707,134	13,563,017
2001	3,189,319	680,550	1,777,293	15,275,073
2002	3,403,433	714,222	1,865,398	17,002,130
2003	3,792,510	798,079	2,047,022	19,976,376
2004	4,231,901	933,251	2,315,781	23,061,021
2005	5,076,230	1,110,255	2,875,116	28,531,831
2006	6,035,291	1,350,047	3,398,956	32,528,758
2007	6,877,229	1,736,087	4,234,236	41,955,128
2008	7,489,852	2,059,187	4,452,343	47,683,681
2009	7,910,407	2,160,973	4,498,171	52,767,093
2010	8,891,041	2,250,109	4,687,789	61,078,188
2011	9,548,866	2,254,406	4,958,738	68,839,341
2012	10,432,259	2,273,821	5,286,061	76,381,183
2013	11,484,514	2,286,309	5,615,494	84,732,652
2014	12,599,038	2,398,846	6,235,136	92,976,240
2015	13,480,973	2,420,917	6,611,028	98,881,267
2016	14,580,666	2,486,898	7,063,433	105,150,082

This section describes the assessment of biodiesel energy development and the relation with forest fire in Indonesia. This analysis considers impact of biodiesel energy development from both direct emission from biodiesel consumption as well as indirect upstream emission from forest fire related biodiesel production.

According to National Energy Plan 2006, Government of Indonesia plan to have transition from fossil fuel energy to renewable energy. One part of the policy is aims to convert the use of diesel fuel into biodiesel from palm oil, which plan to have around 30% of diesel fuel into biodiesel as of 2030. In Indonesia, the consumption of biodiesel is very low and started to have increased significantly in 2010. Biodiesel development will have significant impact in the land use change. Various studies indicate that this biodiesel policy would require a huge increase in area of land use change ranging from 9.5 million ha (Afriyanti et al., 2016), 14 million ha (Wicke et al., 2011), and 20.9 million ha (Harahap et al., 2017) all by 2030.

The assumption made in this assessment is that land clearing for palm oil plantation is performed using fire. Various studies indicating that fire is a major driver of land cover change in Indonesia (Wooster et al., 2012). Man-made fire is a cheap and efficient way to prepare land for agriculture and to gain access to land (World Bank, 2016b). Cultural aspects such as the use of slash and burn by farmers to clear the land contribute to the forest fire problem (Islam et al., 2016). Forest fire is complicated problem that can be attributed to land use change either for de-forestation or land clearing for palm oil (Tacconi, 2003). The land clearing for palm oil plantation using fire also supported by a study that indicating that the growth in number of palm oil plantations is also affecting the increased incidence of forest fires (Gellert, 1998).

The impact on biodiesel development on land use change (LUC) can be divided by two type which are direct and indirect impact on soil, water, biodiversity and climate change. Direct land use change (dLUC) refers to the impact caused by switching a particular land area from some previous use to cultivated land for biofuel crop production. Indirect land use change (iLUC) refer to impacts associated with LUC elsewhere as an unintended consequence of biofuel crop production.(Njakou Djomo and Ceulemans, 2012).

The focus on this chapter is the direct biodiesel development impact on land use change that cleared using fire. Several studies evaluating biodiesel impact on land use change in term of the carbon that is emitted into the air indicate that biodiesel did not mitigate emissions (Overmars et al., 2011) and nearly doubled GHG emissions within 30 years due to land use change (Searchinger et al., 2008). Therefore, biodiesel development should be carefully analysed because without sustainable approach, the land expansion would be harmful to the environment.

To understand the full impact of biodiesel development, an evaluation should be made not only on the emission coming from the consumption of biodiesel but also on the emission that caused in the production of biodiesel. Several evaluations that can be used are Life-cycle Assessment (LCA) analysis and Well-to-Wheels (WTW) analysis. LCA is an analysis that includes emission for specific process such as biodiesel engine, but also the production of material, plants and machineries used for biodiesel. WTW is a simplified LCA that consider emission of the extraction and refining but exclude emission of plants and machineries production. WTW is commonly used in transportation sectors.

Impact evaluation can be made using several measurements. Carbon intensity for example is used to measure that emission rate of a pollutant relative to the intensity of specific activity or production process such as GHG per energy produced. A study in low carbon technology for buses indicated that the WTW of biodiesel is higher than diesel fuel. Biodiesel is estimated to have 1500-2500 gCO_2e/km using biodiesel from animal fats, soybean oil, canola oil and palm oil while Diesel Euro VI only 1400-2200 gCO_2e/km (Dallmann et al., 2017).

Scenario data that used in the analysis shown in Table 5-5 below.

Table 5-5 Biodiesel scenario

No	Scenario	Sectors	Base-year (2010)	Scenario description by 2030
1	BASE	Road Transport	0% biodiesel	Remain the same
		Forest Fire	1,5 million Ha per year	Remain the same
1	Biodiesel	Road Transport	As for BASE scenario	25% renewable biodiesel (gas diesel oil decline to 10%)
		Forest Fire	As for BASE scenario	1,5 million Ha per year
2	Sustainable Biodiesel	Road Transport	As for BASE scenario	25% renewable biodiesel (gas diesel oil decline to 10%)
		Forest Fire	As for BASE scenario	Remain the same

5.4 Results

5.4.1 GHG emissions

In the BASE scenario, GHG emissions grow significantly by 2030 compared with 2010 (Figure 5-5). As of 2010 the GHG emissions in Indonesia were 873 Mt CO_2.eq and are expected to be grow to 1,557 Mt CO_2.eq by 2030. By 2030, the sector that produces most GHGs is transport with 572 Mt CO_2.eq, followed by industry with 292 Mt CO_2.eq, electricity generation with 227 Mt CO_2.eq and energy industry own use with 75 Mt CO_2.eq all of which are due to fossil fuel burning. Based on the result of GHG in each sector, transportation sector is the sector that most influencing in producing GHG.

The analysis in this section does not included "biogenic" CO_2 emissions from land use, land-use change, and forestry (LULUCF). LULUCF is a very important source of CO_2 emissions. FAOSTAT estimate that in 2010 net emission from forest land reach 999 Mt CO_2.eq (FAOSTAT, 2017a). In Indonesia UNFCCC Third National Communication the emission from LULUCF in 2014 is estimate reach 979 Mt CO_2.eq.

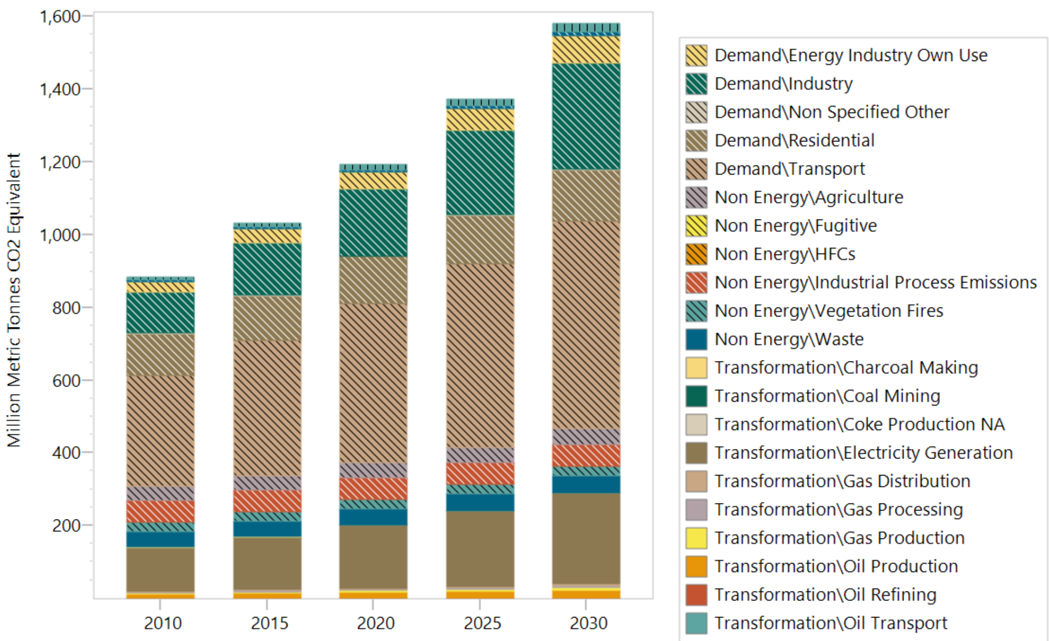

Figure 5-5 Baseline (BASE) scenario for emissions of GHGs by sector for the period 2010 to 2030 in Mt CO_2.eq per year

Figure 5-6 shows the change in CO_2.eq emissions for the major GHGs combined (CO_2, CH_4 and N_2O) from each sector for each scenario. It also shows the size of the avoided emissions for each mitigation scenario relative to the baseline. This shows that the MFRE scenario reduces the most GHG with 1247 Mt CO_2.eq, followed by RENEW scenario with 383 Mt CO_2.eq, and CLEAN scenario with 240 Mt CO_2.eq by 2030. MFRE significantly reduced the GHG as it removes all fossil fuel by using renewable energy. The scenario analysis results indicate that there is a significant potential to reduce the GHG. This is very important for Indonesia in term of environmental pollution particularly resulting from fossil fuels burning. Study indicated that fossil fuel burning is the biggest contribution for GHG in Indonesia (Hasan et al., 2012).

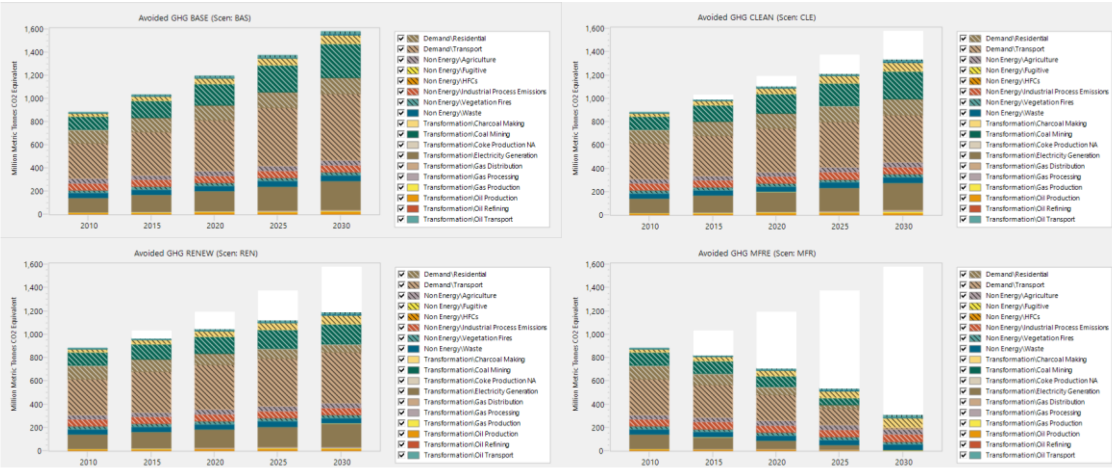

Figure 5-6. Emissions of CO_2.eq by sector for the period 2010 to 2030 for each of the four emission scenarios; also shown are avoided emissions for the three mitigation scenarios (CLEAN, REN and MFRE) relative to the baseline (BASE) scenario (dotted white box).

Figure 5-7 shows that for all scenarios and years CO_2 emissions contribute the most to CO_2.eq emissions followed by CH_4. This figure also shows the avoided CO_2.eq emissions for the three mitigation scenarios (CLEAN, RENEW and MFRE) relative to the baseline (BASE) scenario. (explanation on result) Each scenario lead to decrease in emission of the different GHGs.

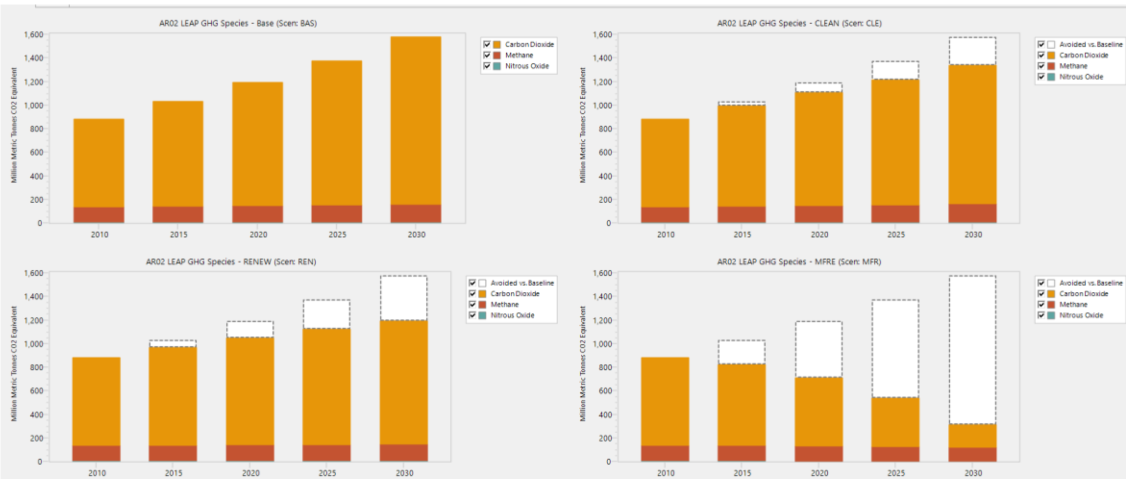

Figure 5-7 Emissions of CO_2.eq (in million metric tonnes) by pollutant species for the period 2010 to 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE); also shown are avoided emissions of the three scenarios relative to the baseline scenario (dotted white box)

Projected GHG emission reductions relative to the BASE scenario by major sector (transport, residential, electricity generation and industry) in 2030 are shown in Figure 5-8. In all scenarios, transport sector is responsible for the biggest GHG reduction followed by industry and electricity generation sectors.

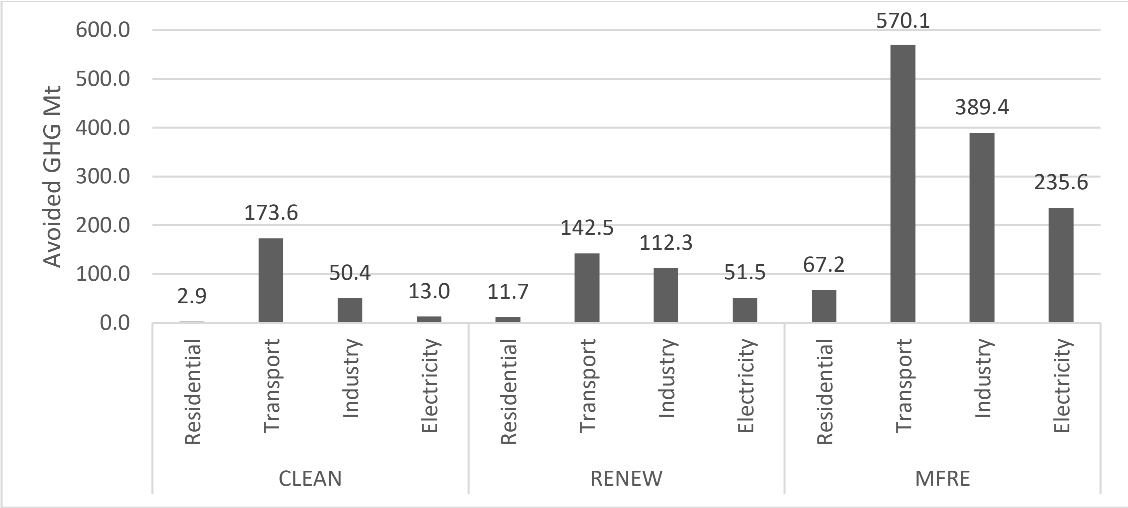

Figure 5-8 Reduction of CO_2.eq emissions (Mt) by sectors as of 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE)

5.4.2 All emissions

It can be seen that the MFRE scenario leads to the biggest reductions for all the emitted species with an average reduction of 59.6%. Each scenario leading to different emissions of each pollutant as shown in Figure 5-9.

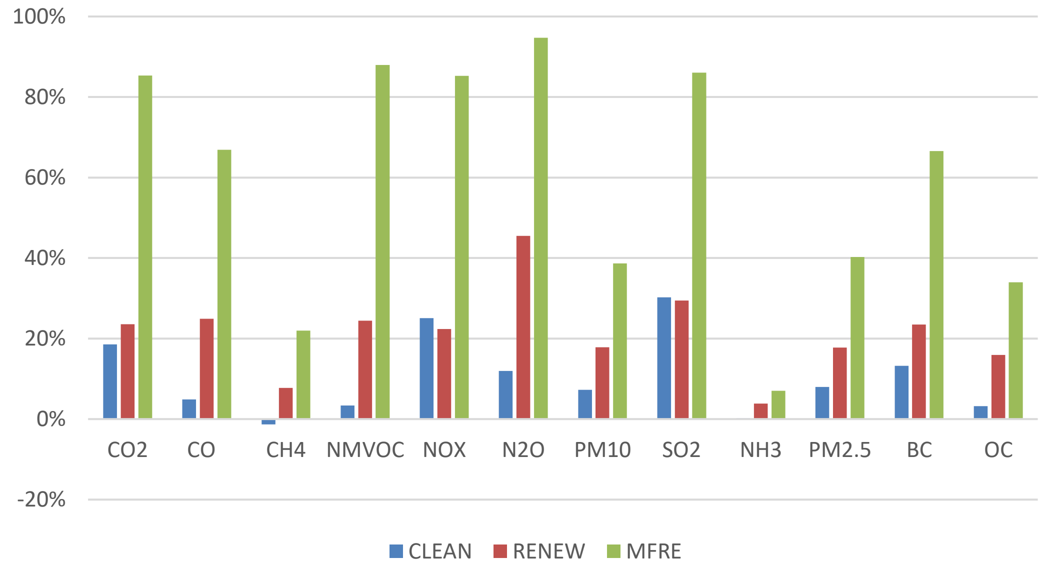

Figure 5-9 Overall scenario reduction

The smallest reduction is NH_3 with 7% and the biggest reduction is SO_2 with 95% reduction. The explanation is due to NH_3 mainly from agriculture sector such as manure management and fertilizer which is not focus in energy transition scenario. SO_2 is mainly from transportation sector and fuel combustion which is the focus in the energy transition. The results of the emission estimates presented in Table 5-6 shows variations in emissions for the different scenarios.

Table 5-6 Air emission estimates in Mt with percentage reduction relative to baseline scenario in 2030

No	Effects	Baseline	CLEAN	Pctg	RENEW	Pctg	MFRE	Pctg
1	CO_2	1,297.93	1,056.71	19%	992.46	24%	189.85	85%
2	CO	61.03	58.03	5%	45.82	25%	20.19	67%
3	CH_4	7.32	7.41	-1%	6.76	8%	5.71	22%
4	NMVOC	17.85	17.25	3%	13.48	24%	2.15	88%
5	NO_X	10.48	7.84	25%	8.13	22%	1.54	85%
6	N_2O	0.02	0.01	12%	0.01	46%	0.00	95%
7	SO_2	3.59	2.50	30%	2.54	29%	0.50	86%
8	NH_3	2.32	2.31	0%	2.23	4%	2.16	7%
9	$PM_{2.5}$	3.13	2.88	8%	2.57	18%	1.87	40%
10	PM_{10}	3.63	3.36	7%	2.98	18%	2.23	39%
11	BC	0.47	0.40	13%	0.36	23%	0.16	67%
12	OC	1.57	1.51	3%	1.32	16%	1.04	34%

CLEAN and RENEW scenario provide emission reduction but not as big as MFRE. CLEAN scenario resulted in an average reduction of 10.4%, the highest reduction is SO_2 with 30% reduction. However, the emissions of CH_4 actually increase by 1% in this scenario, the only emission increase seen for the three scenarios. This is due to increased fugitive emission from oil and natural gas exploration and production. RENEW scenario average reduction of 21.4%. The lowest reduction is NH_3 with 4% reduction, while the highest reduction is N_2O with 46% reduction.

5.4.3 Comparison with other emissions estimates

Comparison with other emissions estimates is with GAINS Eclipse, Permadi (2017) and Permadi (2018) and Indonesia UNFCCC Third National Communication (TNC) (2017) as shown in Table 5-7 below.

Table 5-7 Comparison with other emissions estimates

No	Effects	2010				2030		
		BASE	Permadi	INDC	GAINS	BASE	Permadi	INDC
1	CO_2	626.90	540.28			1297.93	810.41	
2	CO	49.70	24.85		23.74	61.03	29.00	
3	CH_4	6.20	3.98		8.66	7.32	5.53	
4	NMVOC	11.30	4.08		4.56	17.85	5.76	
5	NO_X	4.80	3.32		1.91	10.48	5.25	
7	PM_{10}	3.20	2.15		1.90	0.02	2.84	
8	SO_2	1.80	1.01		1.66	3.63	1.94	
9	NH_3	2.00	1.28		1.38	3.59	2.21	
10	PM	2.70	1.73		1.56	2.32	2.25	
11	BC	0.30	0.25		0.29	3.13	0.31	
12	OC	1.50	0.72		0.59	0.47	0.90	
13	GHG	762.60		687.00		1,458.00		2,034.23

In the table, most of results from this study is higher than Permadi studies due to several sources that included in this study that not available in Permadi such as municipal solid waste in landfill, wastewater which a contributor for CH_4 and waste incineration which a contributor for SO_2, NO_x, CO, NMVOC, NH_3, and PM. The comparison with Indonesian UNFCCC in 2030 is also above the range. The explanation of this the different assumption that used in this study, as shown in Table 5-8 below.

Table 5-8 Comparison of assumption that used in emission estimates

Assumption	LEAP	UNFCCC TNC 2017	UNFCCC SNC 2010
GDP growth average	5.30%	5.50%	7.50%
GDP growth detail	5.39% (2010), 4.87% (2015), 5.03% (2016), 5.06% (2017), 5.24% (2018), 5.26% (2019)	6.2% (2010), 6.2% (2011), 6.0% (2012)	6.6% (2010-2015), 7.2% (2015-2030)
Population growth average	1.00%	1.27%	1.02%
Population growth detail	1.25% (2010-15), 1.06% (2015-20), 0.9% (2020-25), 0.75% (2025-30)	1.38% (2010-2014), 0.96% (2025-2030)	1.05% (2020-2025), 0.94% (2025-2030)
Energy demand growth	2.96%	5.50%	5.70%
- Transport growth	2.31%	6.50%	6.40%
- Residential growth	0.94%	1.60%	-
- Industry growth	4.84%	6.80%	6.4%, 9.3% (2000-2005)
- Electricity growth	3.72%	5.50%	-

Indonesia uses GDP, population and sectoral energy consumption growth based on Indonesia national statistic office (BPS), while in this study population growth is from UN-DESA and GDP growth is from World Bank data. In the Intended nationally determined contribution (INDC), Indonesia use UNFCCC SNC 2010.

5.4.4 $PM_{2.5}$ concentrations

Figure 5-10 Concentrations of $PM_{2.5}$ (in microgram/m^3) shows the change in $PM_{2.5}$ concentrations from all pollutant combined for each scenario over time. It also shows the size of the avoided emissions for each scenario. In the BASE scenario, $PM_{2.5}$ concentration as of 2010 is 12.1 $\mu g/m^3$ and it increased to become 14.7 $\mu g/m^3$ in 2030. Relative to the BASE scenario, all three mitigation scenarios led to a reduction in $PM_{2.5}$ concentrations by 2030: the MFRE scenario reducing $PM_{2.5}$ concentrations by 6.0 $\mu g/m^3$, RENEW by 2.1 µg/m3 and CLEAN by 1.5 $\mu g/m^3$. MFRE reduce $PM_{2.5}$ concentration to be lower than 2010 concentration. MFRE significantly reduces $PM_{2.5}$ concentration due to removal of fossil fuel by changing into renewable energy

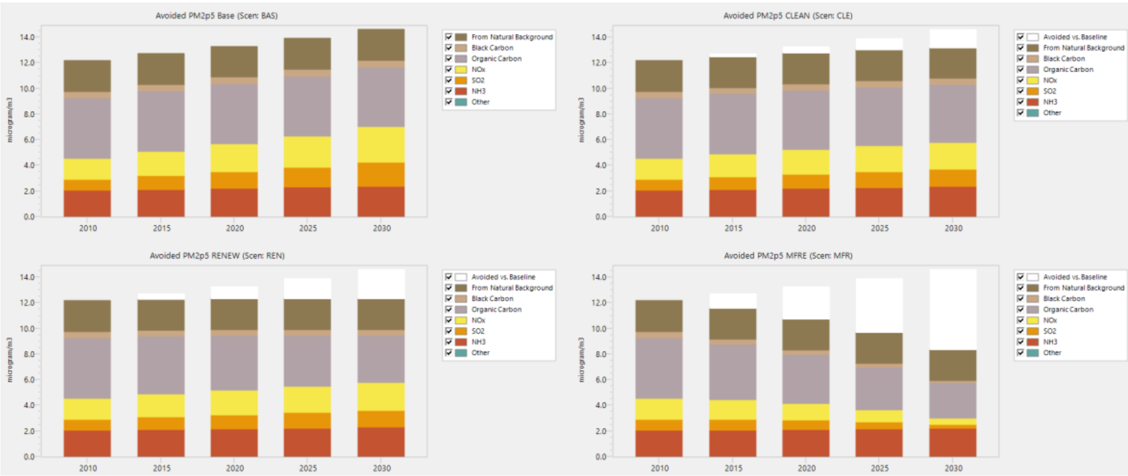

Figure 5-10 Concentrations of $PM_{2.5}$ (in microgram/m^3) for the period 2010 to 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE); also shown are avoided emissions of the three scenarios relative to the baseline scenario (dotted white box)

5.4.5 Avoided premature death

Figure 5-11 shows the change in the number of premature deaths linked to air pollution for each scenario over time. The number of deaths linked to ambient $PM_{2.5}$ air pollution in 2010 is estimated in this study at 45 thousand people which is similar with the number with GBD estimation of 40.6 thousand people (GBD, 2015).

In the BASE scenario the number of deaths caused by air pollution more than doubles to 150 thousand people by 2030. The MFRE scenario provides the biggest reduction of mortality by 134 thousand people, CLEAN reduce by 23 thousand people, RENEW by 31 thousand people.

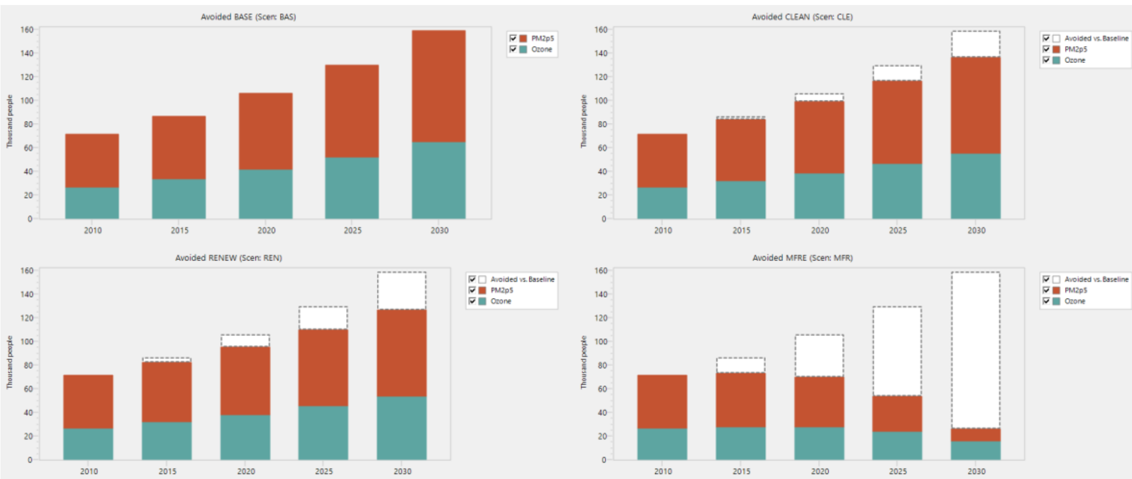

Figure 5-11 Number of premature deaths for the period 2010 to 2030 for each of the four scenarios; also shown are avoided deaths for the three mitigation scenarios (CLEAN, RENEW and MFRE) relative to the baseline (BASE) scenario (dotted white box).

Figure 5-12 shows which sector's emissions reductions contributed most to the avoided mortality. Based on the analysis transportation sector provided the biggest avoided death by

70.5 thousand death followed by industry and electricity generation sector. Transportation sector is the biggest sector that produce GHG and air pollution.

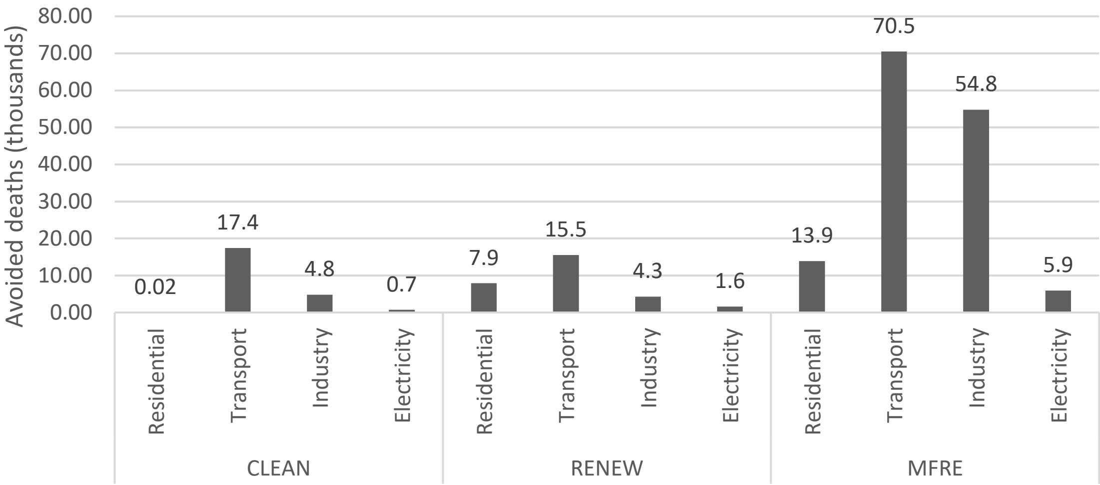

Figure 5-12 Avoided deaths by sector as of 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE) relative to the baseline (BASE) scenario

5.4.6 Avoided global temperature change

Figure 5-13 shows the change in Indonesia's contribution to global climate temperature, relative to 2010, for each scenario over time. It also shows the size of the benefit for global temperature for each scenario. Indonesia's contribution to global climate temperature is expected to increase by +0.010241 ºC by 2030 in the BASE scenario. There was no co-benefit for global climate from any of the mitigation scenarios with all three contributing to slightly increased global warming relative to the BASE scenario. The MFRE scenario increases global temperature by +0.002318 ºC, RENEW scenario increase by +0.000691 ºC, and CLEAN scenario increases by +0.001549 ºC above that produced in the BASE scenario by 2030.

The explanation of the increase of global temperature varies by scenario. In the MFRE and RENEW scenario the explanation for this is the removal of fossil fuel from transport that releases NO_x into the atmosphere. In short term, NO_x reacts with CH_4 in the atmosphere therefore is lowering the global temperature; without this NO_x CH_4 concentrations persist and global temperatures can increase. However for CLEAN and RENEW scenario, another factor leads to a lowering of the global temperature and that is increased OC emissions from fossil fuel burning .

Figure 5-13 The change in Indonesia's contribution to global temperature increase by scenario, relative to 2010, from 2015 to 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE); also shown are avoided climate temperature of the three scenarios relative to the baseline scenario (dotted white box)

See Figure 5-14 for climate temperature by pollutant species. This figure shows the relative contribution of each pollutant to global temperature increase or decrease.

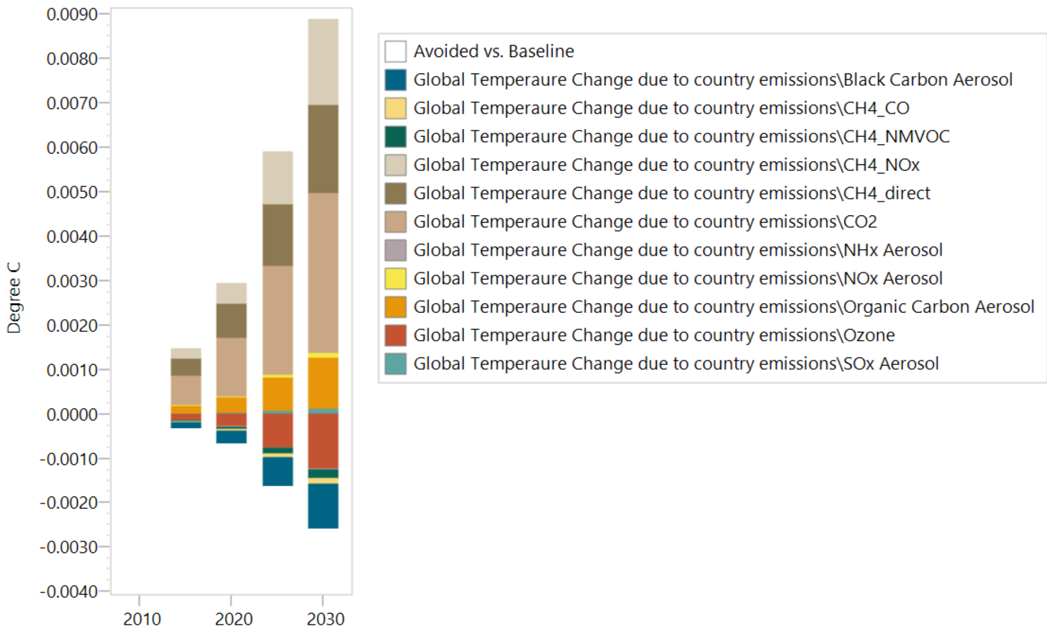

Figure 5-14 Climate temperature for the period 2010 to 2030 by pollutant species for MFRE scenario; also shown are avoided climate temperature of the three scenarios relative to the baseline scenario (dotted white box)

The scenarios that tested in this analysis shows a decrease in term of air pollution and greenhouse gas emission. However, in term of global warming, all the scenarios show an increase global temperature. The explanation of this is due to the timeline that used in this analysis which for 20 years. The benefits for global climate change take longer which estimated for more than 40 years by using MFRE scenario as shown in Figure 5-15.

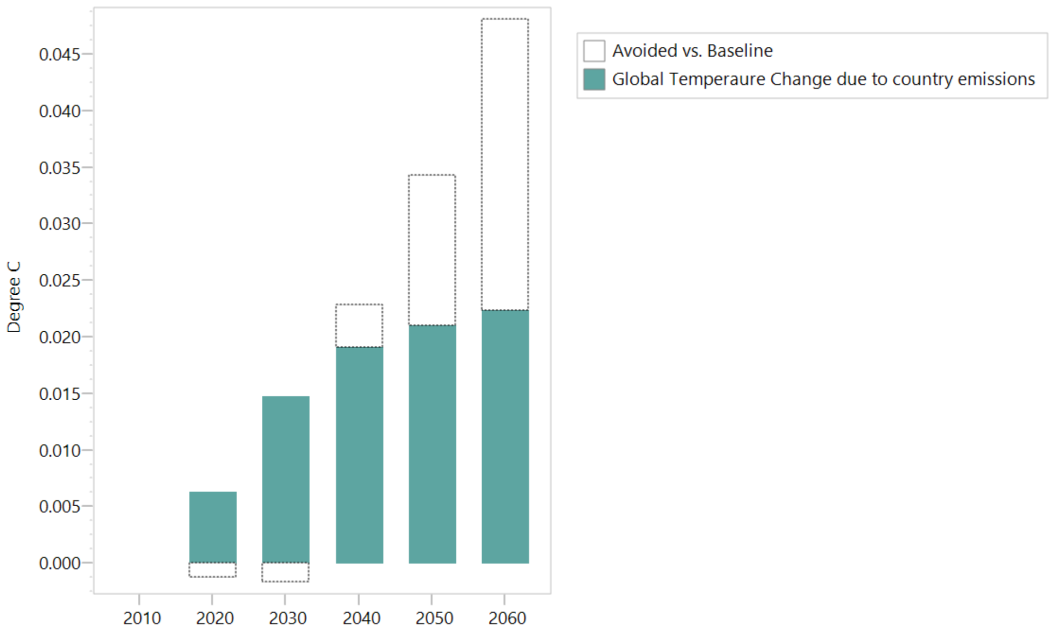

Figure 5-15 The change in Indonesia's contribution to global temperature increase relative to 2010, from 2010 to 2060

5.4.7 Biodiesel impacts

The likely impact of biodiesel energy development is shown in Table 5-9 below.

Table 5-9 Impact on $PM_{2.5}$ concentration, GHG emissions and human health (number of annual premature deaths from exposure to ambient $PM_{2.5}$ in Indonesia)

	2010	2030		
	Baseline	Baseline	Biodiesel	Sustain Biodiesel
$PM_{2.5}$ ($\mu g/m^3$)	12.1	14.7	14.6	14.0
GHG (Mt $CO_{2.eq}$)	789.0	1,457.6	1,348.5	1,344.2
Premature death (Thousand people)	45.0	96.3	95.4	90.7

The impact of biodiesel in term of human health at 2030 is estimated to be a decrease of in premature mortality of 900 people per year which is 0.93% lower than the baseline estimates for 2030. However, a transition to the use of sustainable biodiesel, where there is no associated forest fire, decreases premature mortality by 5,600 people which is 5.8% lower than baseline estimates for 2030. This indicates that a transition to sustainable biodiesel production would have a significant impact on human health.

5.5 Discussion

It is critical for Indonesia to find potential energy pathways that could achieve sustainable energy development. For this purpose, three energy scenario representing possible future of the energy system is simulated using LEAP Model. Some important conclusion which could be drawn from this impact assessment are: i) Air emission grow significantly, based on baseline scenario $PM_{2.5}$ is expected to grow to be 21% higher in 2030 compare with 2010; Ozone is 65% higher in 2030 compare with 2010; GHG is expected to grow 85% higher in 2030 compare with 2010; ii) Bigger environmental impact compare with 2010 condition such as number of death is grow 2.2 times higher. iii) The increased use of clean and renewable energy is likely to be direction for development of energy policy in Indonesia for next 20 years.

Of the three mitigation scenarios explored in this analysis, the maximum feaible reduction (MFRE) scenario produced the biggest reduction in premature deaths (82%) relative to the impacts of air pollution projected in the baseline (BASE) scenario by 2030. However, the other two mitigation scenarios also resulted in significant benefits with the renewable energy scenario (RENEW) resulting reduction 19.1% death, clean energy scenario (CLEAN) reduction 14.2% death.

Energy transition to maximum renewable energy will provide the biggest benefit in term of human health and global warming in the long term. Based on the analysis it can be concluded that an integrated analysis for both air pollution and greenhouse gas is required to improve the quality of decision being made. Policy makers should be able to have wider perspective in terms of energy transition and benefit that want to be achieved both in short term or in long term. Renewable energy scenario (RENEW) outperforms clean energy scenario (CLEAN) in term of avoided deaths and GHG emission. However maximum benefit can be achieved by using 100% transition to renewable energy as demonstrated in the MFRE scenario. Since the total benefit is greater for the renewable energy than clean energy scenario, policy makers should promote renewable energy.

In 2010, it is estimated that 45 thousand people died prematurely from ambient $PM_{2.5}$ air pollution increasing to 96 thousand people by 2030 according to the BASE scenario. The MFRE scenario shows the largest reduction of premature mortality at 134 thousand people, followed by RENEW scenario at 31 thousand people and CLEAN scenario at 23 thousand people. Overall, transition to renewable energy policies will provide greater benefit for Indonesia in term of human health. Policy maker should also consider more integrated approach for sustainable energy, GHG and air pollution reduction strategy.

It is important to understand each sector's characteristics to implement appropriate mitigation policy. Transportation sector for example is the first biggest energy consumption and also the biggest sector that cause premature mortality. Any energy scenario that focusses on transportation sector may provide the bigger benefit by providing the biggest reduction of death.

Industry is the biggest sector that consume electricity energy. In 2030 48% of electricity generated or 14.3 Mtoe from 29.9 Mtoe is to be used in the industry sector. Therefore, any scenario that shifting to sustainable electricity generation will need to consider how its application in the industry sector.

Residential sector is the fourth biggest sector after transportation, industrial and electricity generation sector that consumed energy. At the national level in 2011 primary energy source that use for cooking is LPG at 46% followed by firewood at 39% and kerosene at 11%, biomass is still used significantly at rural level (Bedi et al., 2017). In this study, as of 2010, based on the share of people that use certain type of cooking which are kerosene 8%, LPG 29%, wood 39% and electricity 22% or based on source of energy which are kerosene 4%, LPG 7%, wood 84% and electricity 5%.

5.5.1 Comparison with government projection

Generally, government projection in renewable energy (RENGOV) or in clean fossil energy (CLEANGOV) tend to be more optimistic by putting higher number in share of renewable energy for example in RENGOV is 21% while in adjusted renewable energy scenario (RENEW) is only at 14%. In CLEANGOV energy scenario, the share of gas energy is 33% while in adjusted clean energy scenario (CLEAN) is only at 25% as shown in Table 5-10.

Table 5-10 Comparison with government scenario

Scenario	**Energy (Mix)**				
	Oil	**Coal**	**Gas**	**RE**	**BM**
Baseline (BASE)	34%	15%	18%	8%	24%
Planned Renewable (RENGOV)	38%	17%	20%	21%	4%
Adjusted Renewable (RENEW)	33%	16%	24%	14%	13%
Planned Clean (CLEANGOV)	40%	18%	33%	5%	4%
Adjusted Clean (CLEAN)	37%	18%	25%	7%	13%

The result of this optimistic projection that tend to increase the possibility of renewable energy share in Indonesia will cause the reduction in GHG and energy demand projection.

Based on the analysis, the Indonesian government official projection for GHG by 2030 is 2,034 Mt CO_2.eq. The GHG level in 2030 for each scenario as follows CLEGOV is 1,178 Mt, RENGOV 1,079 Mt GHG.eq, CLEAN 1,218 Mt GHG.eq and RENEW 1,138 Mt GHG.eq. The official projection shows relative lower energy demand as shown in Figure 5-16.

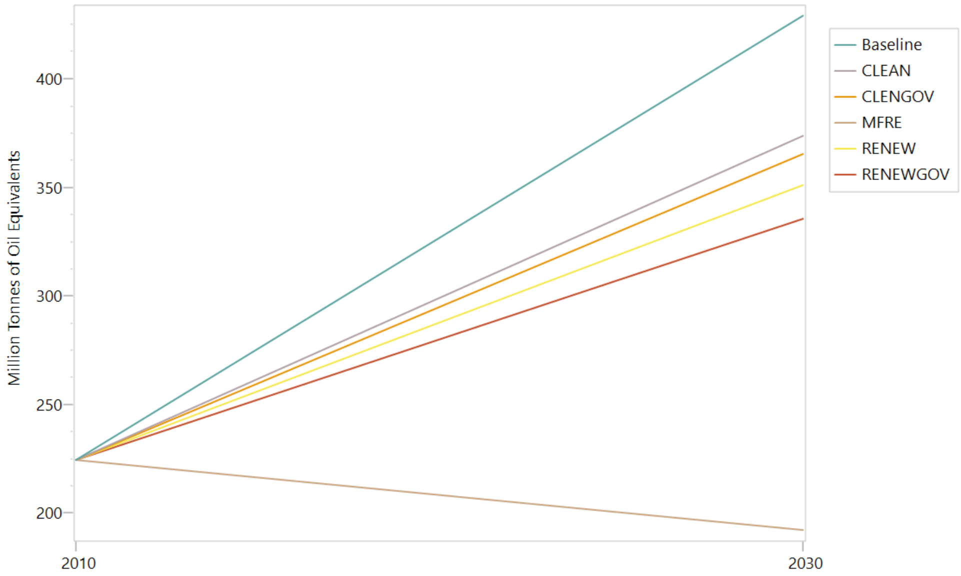

Figure 5-16 Comparison of government projection on energy scenario

The official projection for energy demand is 378 Mtoe. In this analysis the energy demand for each scenario as follows CLEGOV is 366 Mtoe, RENGOV 336 Mtoe, BASE is 430 Mtoe, CLEAN 375 Mtoe and RENEW 352 Mtoe. The official projection shows relative lower emission as shown in Figure 5-17.

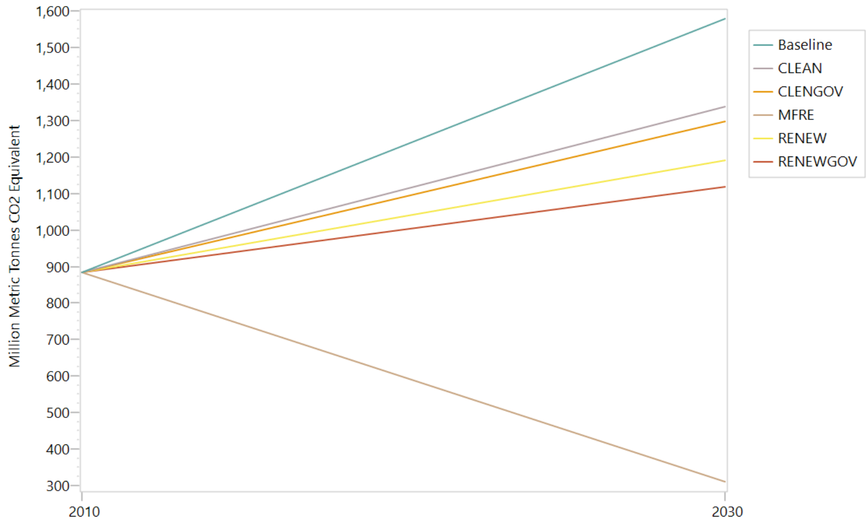

Figure 5-17 Comparison of government projection on GHG emission scenario

This result is aligned with various study that shows government of Indonesia put an ambitious target for GHG reduction and energy demand reduction (Dutu, 2016). This result will be important for policy maker to improve the projection on future energy demand, GHG and air pollution in Indonesia. The result also would be valuable for government of Indonesia to evaluate the current energy and emission plan. It also be noted that currently there is no government project on air pollution and its impact.

5.5.2 Energy demand

This analysis shows that, as of 2010, the energy demand in Indonesia was 224 Mtoe and is expected to grow to 430 Mtoe in 2030. The MFRE scenario reduces the most energy demand with 238 Mtoe, followed by RENEW scenario with 78 Mtoe, and CLEAN scenario with 55 Mtoe. Comparison of these scenarios shown in Figure 5-18 below. In general energy demand in the transportation sector is the biggest followed by industry and residential sector. Although reducing energy demand is not the priority in the clean and renewable energy scenario however due to efficiency in the renewable energy compare with fossil fuel, MFRE scenario project the most significant energy demand reduction.

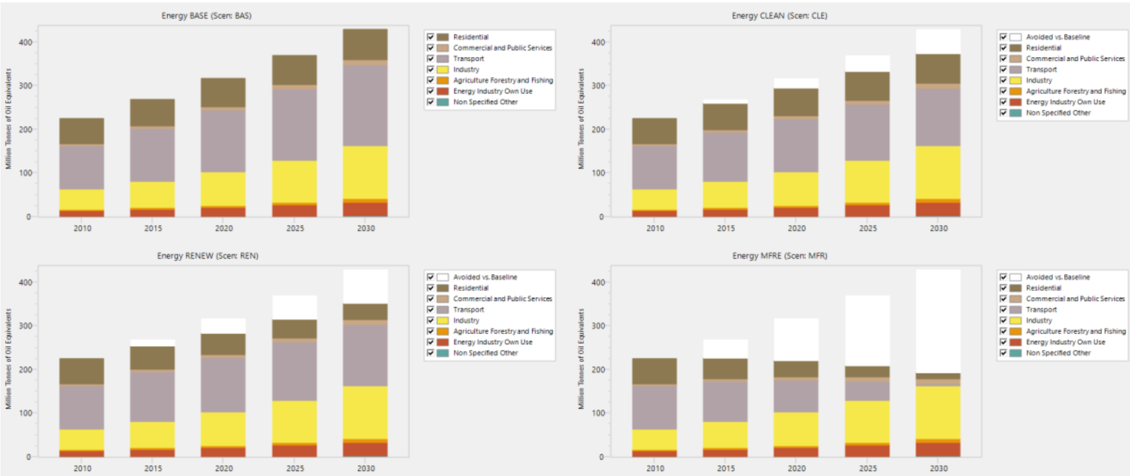

Figure 5-18 Energy demand for the period 2010 to 2030 for each of the three emission scenarios (CLEAN, RENEW and MFRE); also shown are avoided energy demand of the three scenarios relative to the baseline scenario (dotted white box)

Based on this result, it is important for the policy maker to use an integrated approach for energy and environment policy to ensure the biggest benefit resulted from policy be achieved.

5.5.3 Biodiesel impacts

The result of this assessment indicates that unsustainable biodiesel development in Indonesia might be harmful to both the environment and human health. This result is in line with other studies on biodiesel production impacts. One study indicated that converting forest or peatland to cultivated lands for biofuel crop production resulted in little GHG emission saving or even led to carbon deficit (Njakou Djomo and Ceulemans, 2012). Another study indicated that existing biodiesel production pathways are unlikely to deliver significant net climate benefits due to indirect emissions (Posada, 2012). The conversion of peat swamp forest to palm oil plantation has major impacts on the environment by producing more GHG (Page et al., 2011). Conversion also affects the loss of biodiversity such as orangutans. Transition to renewable energy needs to carefully assess the emission of potential renewable energy options to ensure that GHG emission reduction goals are realized (Dallmann et al., 2017).

Biodiesel development in Indonesia is a complex issue and to minimize the impact of biodiesel development in Indonesia, an understanding of the biodiesel policy and the nature of forest fire is important to develop a comprehensive energy policy. These two factors will be discussed in section below.

Biodiesel policy

The growth of biodiesel production in Indonesia is closely related with economic issues which in this case is palm oil expansion, and energy issues which in this case means the scarcity of energy (Demirbas, 2007). Agriculture is important sector for Indonesia and palm oil especially is very important for the Indonesian economy. Palm oil is a major Indonesian export, around 9% of Indonesian export in 2014 being from palm oil (World Bank, 2014).

In term of land size according to National Office Statistics as of 2014, palm oil is the biggest land use in Indonesia accounted for 8.15 million ha. By comparison, rice paddy field, the main staple food only accounted for 8.08 million ha, maize around 4.38 million ha and rubber plantation 3.6 million ha. Indonesia is the biggest palm oil producer in the world accounting for 34 Mt (FAO, 2014) of which 27 Mt is exported and 7 Mt is used domestically. In domestic consumption 2 Mt palm oil is used for biodiesel (MOI, 2014). In 2017 palm oil production reach 41.9 Mt.

Indonesia has a long history of exploitation of natural resources such as forestry and plantation. In the past during Dutch colonialism, Indonesia is major exporter of sugar and coffee. After Indonesia independence in 1945, it started producing logging and pulp and paper and recently shifted to oil palm production (Varkkey, 2012). The boom of palm oil plantation began in around 2000 when the palm oil plantation extent reached 3 million ha (Mccarthy and Zen, 2010). In early 2000, most of the palm oil produced was exported; with about 90% of palm oil exported in the form of Crude Palm Oil (CPO). However recently, lower CPO prices have encouraged more downstream processing where in 2012 the CPO is only accounted for 40% and the remaining 60% for Palm Oil processed products (Ministry of Trade, 2012).

Palm oil processed products can be divided into three types: Oleofood, Oleochemical and Biodiesel. Oleofood is any palm oil product that used as butter, margarine, creamer and other variant of products. Oleochemical is any fatty acid or fatty alcohol that used as detergents, soaps, and cosmetics. The third product is Biodiesel or Fatty acid methyl ester (FAME). Biodiesel is one of the most promising palm oil products due to the scarcity of energy in Indonesia. For example, in 2013, the export composition of palm oil processed product is Fatty Acid 537 kt, Fatty Alcohol 259 kt, Glyserol 485 kt and Biodiesel 1,687 kt. The growth of biodiesel production is also indicated in both domestic use and export, for example, as of 2014, according to IEA Indonesia produced 2,936 kt of biodiesel of which 1,512 was exported and

1,424 kt used for domestic consumption. It can be argued that the biodiesel rapid growth in 2010 is an inevitable impact of palm oil expansion (Obidzinski et al., 2012).

Indonesia is facing an energy crisis due to the decreasing conventional oil production and high energy consumption, and in 2004 Indonesia become a net oil importer country. Therefore, various energy policies to use more renewable energy from biodiesel have been enacted since 2006 including the mandatory use of biodiesel in transportation sectors starting with the 10% blend in 2014 to reach 30% in 2025. Biodiesel is also now being used in the power generation sectors to replace diesel power plant (Indrawan et al., 2017).

Therefore, from the Indonesian government perspective, the use of biodiesel is seen as a solution to the country's energy scarcity. However, for Indonesia, biodiesel development is problematic due to its large associated environmental impact. For example, such concerns in Europe have led to the recent European Parliament resolution of 4 April 2017 on palm oil and deforestation of rainforests, which bans biodiesel imports from Indonesia. The EU resolution is continuance of The Amsterdam Declaration in Support of a Fully Sustainable Palm Oil Supply Chain by 2020 signed in 7 December 2015. This will probably just lead to an increase the domestic consumption of palm oil in form of biodiesel (Samah and Nuryati, 2009).

The consequences of having biodiesel as a preferred fuel in transportation sectors in Indonesia will have significant impacts on the environment and human health. The ambitious target for mandatory use of biodiesel will require further expansion of palm oil plantations. It is estimated that to reach this target, it requires expansion of 20.9 million ha for biodiesel development (Harahap et al., 2017). The estimation of land required for biodiesel development is vary from several study due the difference in calculating biodiesel yield, sector coverage and fuel consumption estimation.

Moreover, oil palm expansion is often held responsible for deforestation, biodiversity loss, increased greenhouse gas emissions, and conflicts over land rights between oil palm companies and local communities (Gatto et al., 2015). Indonesia has experienced rapid forest loss over the last four decades and lost 6 million ha of natural forests between 2000 and 2012 (Spracklen et al., 2015).

Another issue with rapid oil palm expansion relates to trans-boundary air pollution. Trans-boundary air emissions from Indonesian forest fires were responsible for enhanced concentrations of particulate-bound elements during past smoke haze episodes (Behera et al., 2015). A trans-national cooperation to solve the regional air pollution problem in Southeast Asia, the Association of South East Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution, was established in 2002 (Mayer, 2006). Significant growth of biodiesel production in Indonesia may have environmental impacts both in Indonesia and regionally, depending on the success or otherwise of such agreements as well as national policies.

Biodiesel in Indonesia is a complex dilemma involving competing demands of economic growth, energy security and climate change mitigation (Gunningham, 2013). Further, a study indicated that unsustainable expansion of oil palm plantations is more likely in the absence of policies (e.g. a moratorium) to avoid deforestation and peat conversion (Afriyanti et al., 2016). Another study indicated that many plantation companies tend to maintain political connections with Indonesia government to receive concessions and rights easily and quickly (Islam et al., 2016).

Based on the analysis of biodiesel energy development impact using LEAP-IBC it can be concluded that a careful plan should be made based on both environmental and energy concern. A sustainable energy should not be seen as simple as converting from fossil fuel to renewable energy, but also need to see as an integrated activity that have wider impact.

Forestry policy

In Indonesia the expansion of palm oil plantations mainly from forest area, as plantation generates profits from timber either as an end or as means to generate additional capital (Obidzinski et al., 2012). The analysis on impact of biodiesel on forest availability in this section assume that agricultural land conversion to palm oil is limited and mainly from forest.

Impact of biodiesel development on forest availability depending on the classification of the forest such as conservation forest, protected forest and production forest. Indonesia currently has 120 million ha of forest. Conversion to biodiesel only can be achieved if there is a forest left. If the conversion is solely based on the 'production forest' category (only 30 million ha), the biodiesel target is unlikely to be achieved before 2030.

Analysis of biodiesel impact in Indonesia should also take careful consideration of forest fires due to their significant contribution to emissions and wide annual fluctuation pattern. The amount of emissions coming from forest fires in certain years can be very big making other source of emission seems very small in comparison. For example, in the 1997 forest fire event, the amount of emissions released was around 0.8 – 2.57 Gt carbon which was equal to 13-40% of Indonesia's annual global carbon emission from fuel (Page et al., 2002). The 1997 forest fire was one of the biggest forest fires in Indonesia's history. Forest fire is a major environmental problem in Indonesia (World Bank, 2016b).

It can be argued that to eliminate forest fire requires a major reform in land use practice in the context of Indonesia's economic development, while in the short term, fire prevention and mitigation measures must be developed as early warning triggers (Field et al., 2016).

5.6 Conclusion

In this study, three mitigation scenarios were assessed using the LEAP modelling framework to represent alternative energy transitions of Indonesia's future energy system from 2010 to 2030. The results show that energy policies implemented in Indonesia will have a significant impact on both GHG emissions and air pollution.

This study shows that the road transportation sector has the greatest potential benefit in terms of human health, followed by the industry, electricity generation and residential sectors. In the transportation sector, substitution of gasoline and diesel with renewable energy such as biodiesel or bioethanol might provide benefit as long as it is coming from sustainable sources. In the power generation sector, the best policies to reduce GHG emissions include substitution of existing oil and coal plants with renewable energy such as geothermal or wind energy. In the residential sector the best policies is to substitute the use of traditional wood biomass stove with renewable energy such as biogas or solar cooking will provide a benefit and sustainable energy.

Biodiesel impact evaluation has been performed to identify overall impact of biodiesel both direct and indirect impact in Indonesia. It indicates unsustainable biodiesel development is harmful for human health and the environment. Therefore, careful policy on biodiesel, land clearing and agricultural policy should be made. An analysis of biodiesel policy in Indonesia should take into consideration both air emission reduction and the larger environmental impact on the land use from expansion of palm oil plantations. A sustainable approach to biodiesel development is required to ensure that the benefit outweighs the cost required for biodiesel adoption. Good governance is also required to ensure the sustainable biodiesel development.

In this chapter, the changes in emissions resulting from alternative energy transitions were simulated to study the impact on human health and global temperature. The simulations show that maximum benefit can be achieved by energy transition to sustainable energy sources such renewables or clean fossil fuel. The renewable energy scenario seemingly provides a bigger benefit then clean energy.

In order to explore maximum potential benefits for human health, a maximum feasible renewable energy scenario was also simulated. As shown in the Chapter 4 Emission scenario, it could be argued that energy transition that based on renewable energy can be used to solve the problem in unsustainable energy development. In this Chapter 5 Impact assessment, it is shown that transition to clean or renewable energy can have the advantage of integrated benefit calculation both of human health.

Notes:

Chapter 6 Conclusion

6.1. Introduction

Air pollution and greenhouse gases is a serious problem in Indonesia. The current level of air pollution and greenhouse gases is increasing and lead to various problem such as human health and climate change. In Indonesia, air pollution is one of the five risk factors that cause most of the premature mortality which are high blood pressure, dietary risks, tobacco and high fasting plasma glucose (blood sugar level) (GBD, 2015). Jakarta, the capital of Indonesia also one of the most populated and polluted regions in the world especially in term of particulate matter pollution (Both et al., 2013).

In term of GHGs, Indonesia is identified as the sixth largest GHGs emitter, accounting for 4.5% global emissions, with Indonesia's energy sector making up to 25% of total emissions (World Bank, 2007). These GHGs emissions come from energy use in power generation at 42%, transport at 25%, industry at 21% and the rest from the residential sector. The trend in the long run show an increase of GHGs due to various factor from economic growth to urbanization (Resosudarmo et al., 2009).

Energy related sector is a key sector that responsible the most for the increase of air pollution and GHGs. Energy-related GHGs currently accounts for more than three quarter of total emissions. In the US at 76% (US-EIA, 2019), in Europe at 77% (EMEP/EEA, 2019b) and in Indonesia at 61% (MOE, 2011). Carbon dioxide is by far the most significant energy-related greenhouse gas, with a share of about 97 % (EMEP/EEA, 2019b). Therefore, as significant key sector, energy transition is important in relation to the reduction of air pollution and GHGs.

This research aims to evaluate the feasible options for future sustainable energy systems for Indonesia. It explores the different sustainable options for energy transition in Indonesia to understand the relation between energy development and the consequences of this development in term of human health and climate change. Assessment such as inventory, scenario and impact analysis that made in this thesis can be used to analyze past, present and future energy systems. The result of the assessment such as sectoral analysis, future impact analysis on human health and climate change may serve as planning, scenario analysis and policy assessment that important for Indonesia and developing country in general.

6.2. Conclusion

Contribution of energy sector

The contribution of energy sector to atmospheric emission is described in Chapter 3 Emission inventory. Understanding the contribution of energy sector is important to identify which sectors should be prioritized for emissions reduction. This inventory would provide a basis for projecting future emissions within the energy scenario development described in Chapter 4 Emission scenario. Based on the analysis it can be concluded that road transportation and residential sector are the two major sources of air pollutant emissions in Indonesia. Road transportation is responsible for the majority of CO, NO_x and NMVOC emissions, the residential sector for a sizable contribution to CO and NMVOC emissions and forest fires, at least in 2010, being the third largest source of CO emissions. In the road transportation sector, it can be seen that in road transport, diesel vehicles are responsible for producing most NOx at 366 kt in contrast with gasoline vehicles which only emit 186 kt. Thus, diesel vehicles produce almost twice the NO_x emissions of gasoline vehicles.

The analysis also shows that the main emission sources in Indonesia reflect the country’s energy system which is dependent on the use of fossil fuel and the use of wood as a traditional biomass fuel in domestic cooking. The use of fossil fuel is mainly as coal in power generation and petroleum in the transportation sector. In power generation sector, SO_2 emissions are mainly from coal-based power stations including public electricity generation and auto-production of electricity. However, for the other pollutants, road transportation, the residential sector and vegetation (i.e. forest) fires are the three major sources of emissions in Indonesia.

Various policy options can be considered, based on the results of this emission inventory with an emphasis on reducing emissions in transportation, residential and power generation sector with, for example, a focus on fuel substitution. Substituting fossil and wood fuels with cleaner fuels such the use of natural gas or based on sustainable sources of renewable energy would substantially reduce emission.

Current energy policy

Indonesia energy policy has been in development since 1981. Indonesia’s energy policy mainly consists of three major objectives which are energy conservation, intensification of searching for new energy reserves and diversification of energy resources (Othman et al. 2009). Recently, Indonesian government is aiming to have a bigger share of renewable energy in the energy system. The specific energy policy that explicitly targets to a shift to renewable energy was only developed in 2006 and later updated in the Government Regulation no 79/2014 on National Energy Policy 2025-2050.

This is also indicated with the establishment of Indonesia’s National Energy Council (NEC) in 2007, the development of energy policy is finally involving multiple ministries such as the Ministry of Energy, Ministry of Industry, Ministry of Transportation, Ministry of Environment and government agencies such as the National Agency for Planning, the National Agency for Oil & Gas Supervision. NEC was tasked with designing Indonesia’s energy scenarios which are then regulated in the government regulation 79/2014 for the period until 2025 and comprise the National Energy Policy. The energy policy has focused on the transition to renewable energy; the share in renewable energy is intended to increase by up to 23% by 2025.

Emission scenarios and impact

The current energy development in Indonesia have a significant impact to atmospheric emissions as described in Chapter 5 Impact assessment. For example, in the baseline scenario, without mitigation policy, GHG emissions grow significantly by 2030 compared with 2010. As of 2010 the GHG emissions in Indonesia were 873 Mt CO_2.eq and are expected to be grow to 1,557 Mt CO_2.eq by 2030. In the baseline scenario, $PM_{2.5}$ concentration as of 2010 ist 12.1 $\mu g/m^3$ and it increased to become 14.7 $\mu g/m^3$ in 2030.

The number of deaths linked to ambient $PM_{2.5}$ air pollution in 2010 is estimated in this study at 45 thousand people which is similar with the number with GBD estimation of 40.6 thousand people (GBD, 2015). In the baseline scenario the number of deaths caused by air pollution more than doubles to 150 thousand people by 2030.

Therefore, it is important for Indonesia to have sufficient mitigation to reduce this impact. Energy transition to clean and renewable energy in Indonesia will play important roles in this mitigation. However, it should be noted that the likelihood of energy transition in Indonesia is depending on various factor such as economic, financial, business and also geography. This factor is analyzed in the Chapter 4 Emission scenario.

In the Chapter 4, the maximum feasible renewable energy that consider geographical factor is developed and the feasibility of the transition is analyzed. Based on the analysis, transition to maximum renewable energy will provide the biggest benefit in term of human health. Biodiesel impact evaluation has been performed to identify overall impact of biodiesel both direct and indirect impact in Indonesia. It indicates unsustainable biodiesel development is harmful for human health and the environment.

The proposed approach in this thesis offer a new way to understand the impact of energy development in Indonesia, especially in term of air pollution and human health that never been explored before. The proposed approach is necessary and relevant with the current problem that face by Indonesia. In overall, this method is proposed to help evaluate the energy policy and challenge the assumptions on the capacity target such as energy mix that and helps to assess the choices and options available.

The policy maker should reevaluate its energy development approach along with the environment mitigation plan. It is proposed that this approach of energy, greenhouse gas and air pollution assessment performed to improve the quality of decision that made by policy maker.

The result of this research is an assessment that can be used to model the energy system and transition of clean and renewable energy development. It will define the atmospheric emission impact of energy system and develop energy scenario based on the Indonesia characteristics that currently is not explored. The result of this research can be very useful for making a better energy and environment policy in Indonesia.

6.3. Recommendation

As transition to renewable energy is inevitable due to scarcity of fossil fuel, while transition to cleaner energy is required to reduce the impact of energy development on human health and climate change. It is important to have a comprehensive assessment of energy development. There are three main recommendation that resulting from this study that will help in the assessment of energy and environment in Indonesia as follows.

- To have an integrated assessment of both air pollution and GHG. This integrated assessment would give more benefit as it would cover both air pollution and GHG mitigation which currently performed in silos. This integrated assessment would provide more comprehensive assessment on the energy system which will give more benefit to development of energy and environment policy.
- To focus on key sectors such as transportation, industry and electricity generation that reduced emissions that lead to human health impacts and avoided climate change. Energy scenarios are useful for policy maker to assess the impact of energy transition which will affecting human health. Energy scenario analysis helped to identify which sectors should be prioritized for emissions reduction and to understand the impact of emissions in Indonesia energy system.
- To consider geographical factor in the scenario analysis. As energy scenario might differ by the geographical indicator such as island’s energy source availability in term of future energy mix. It is also important that for further study it is recommended to have the perspective of policy maker that need to consider various option for energy transition.

Further, there are various factors that need to be considered to ensure energy transition in Indonesia. This research indicated that key emission sources should be targeted and done in feasible matter. Based on the analysis, it has been demonstrated that the various factor such as government policy, state-owned company or private sector were found to be responsible for influencing the energy policy development in Indonesia.

The involvement of the state-owned company in energy project or conflicting policies between regional and central government affecting the effectiveness of energy policy in Indonesia as it might create a conflict of interest. Policymaker should consider these factors such as transportation policy, industry policy and electricity generation policy as key sectors in making an integrated policy.

Energy transition will have significant impact on human health and climate change. In the policy development process from various factor such as impact on human health and climate change affecting the policy formulation, policy implementation, and policy evaluation. Policymaker should consider this factor in developing an integrated policy. Policy recommendations can be made to promote sustainable energy development in Indonesia.

In the renewable energy scenario, the government of Indonesia needs to evaluate the policy of using renewable energy in all sectors such as the use of biogas in the residential sector, biodiesel in the transportation sector and renewable energy such as geothermal, wind energy and solar PV in industry and electricity generation sector. The clean energy scenario requires a shift to gas energy in all sector such as LPG in the residential sector, CNG in the transportation sector, and the use of natural gas in industry and electricity generation sector. The government of Indonesia needs to prioritize the natural gas energy usage in the energy system as it has less emission compare with coal or oil. The maximum feasible reduction scenario needs coordination with local government and to gain support with this initiative. The coordination with local government should be made to ensure that the policy is align and not contradict between central government and local government.

6.4. Uncertainty

There are several uncertainties in this thesis which affect the results of this assessment. The uncertainty can be divided into two parts. The first part is uncertainty in the emission inventory and impact assessment such as peatland burning and forest fire. The second part is uncertainty in the scenario development such as fluctuation of energy price, macro-economic growth and technology.

In the emission inventory, peatland burning calculation should further investigated. Indonesia has the largest tropical peatland in the world with estimated size of 22 million ha. Forest fire in Indonesia is mainly around 80% is from peatland forest burning. Therefore, accurate peatland burning calculation will affect the result of emission inventory in Indonesia. For example, in this thesis the $PM_{2.5}$ emission factors that used for forest fire is only 9.1 g/kg while recent study of indicate far greater amount of emission factors of 66 g/kg (Wooster et al., 2018).

The fluctuation of energy price, for example oil price reach more than $100 per barrel in July 2008 but then decline less than $50 in December 2008. This fluctuation also happens for coal, gas and biodiesel price. Renewable energy prices in Indonesia in most cases is more expensive than fossil fuel. Therefore, this fluctuation might affect the Indonesian government energy policy in the future.

6.5. Future work

With the completion of this research, there are many possible areas of improvement that can be explored considering that the works done in this research constitutes only a starting point for a wider study.

In general, Maximum Feasible Renewable Energy (MFRE) can be improved by expanding to various renewable energy sources such as wide range of biofuel such as Cassava, Jatropha Curcass or Algae biomass. Currently there are many potential renewable energy sources in Indonesia that is not explored yet. Some of this renewable energy also geographically specific such as certain biofuel that only can grow in specific place or certain renewable energy in specific area such as tidal energy.

Indoor air pollution from the use of biomass cooking fuel should further investigated. The Indonesian energy system reliant on a large use of traditional biomass such as fuel wood for cooking which dominates the residential sectors energy supply and use. For example, in 2011 it was estimated that 103 million people relied on wood fuel for cooking out of the 245 million total population (IEA, 2015). The implication of not including indoor air pollution is that the number of premature deaths slightly lower. For example, it was estimated that air pollution in Indonesia caused the premature death of 155,609 people in 2010, where 97,783 caused by household air pollution and 70,700 ambient air pollutions.

More detail transportation analysis that is not covered such as detail motorcycle analysis and traditional transportation in rural area. As motorcycle is widely used in Indonesia and can reach average of 50 km per day which significantly affect the calculation in motorcycle subsector (Kimura et al., 2018).

More over, in this research process there are two lesson that would be useful for future research on the data availability and interview process. Data is the biggest challenge in this research. Various issues such as data availability and data quality raised during the research process. Data availability is a condition where the data is not available, for example the historical oil transportation data in Indonesia is not complete, therefore makes difficult to analyze the oil transportation and distribution. Another issue is on the quality of data, where in some of cases that the official government data might provide different data. For example, data from central government compare with data from local government. In some cases, where the data from national office of statistics is different than the data from departmental ministry this research would be prefer data from office of statistics.

One of greatest challenges in the semi-structure interview is the availability of interviewees, especially the higher-level position. It is difficult to have a commitment from high-level position where usually it is delegate to its lower level position to have interview. Various effort is established to ensure that the interview could be performed such as using telephone and video conference or to make sure that the interview request is communicated before. As alternative, interview of the same level position in different department or company can be established to mitigate this situation. However, in this study, the semi-structure interview has been identified as the most suitable for the purpose of this study.

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