ID 2015 Report

pathways to

deep decarbonization

in Indonesia

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Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanization, and also takes part in efforts to reframe development pathways.

The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

The Center for Research on Energy Policy - Institut Teknologi Bandung (CREP-ITB) is one of research centers of Institut Teknologi Bandung (ITB), Indonesia. The Center was established in 1980 and formerly known as the Center for Research on Energy of ITB (CRE-ITB). The major research areas of the Center are analysis of policies of energy and energy-related development issues, including energy and environment and sustainable development.

The Centre for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM - SEAP), is one of research centers of Bogor Agricultural University, Indonesia. The main focus of research areas of the center are analysis of policies related to climate changes and development including analysis of impact of climate variability and climate change and management of risks and opportunities of those events to improve human welfare and environment.

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Executive summary

Introduction

This report presents the results of a deep decarbonization analysis conducted by the Indonesian Country Research Team consisting of researchers from Institut Teknologi Bandung, particularly the Center for Research on Energy Policy–Institut Teknologi Bandung and Centre for Climate Risk and Opportunity Management–Bogor Agriculture University. Our objective is to explore potential development pathways by which the Republic of Indonesia could achieve the deep decarbonization of its economy, to the level where it would contribute to the worldwide endeavor of limiting global temperature increases to less than 2°C. The deep decarbonization pathway analysis presented in this report is the result of scientific assessment; it is not the Indonesian government's plan nor its commitment to climate change mitigation.

The research addresses two main questions:

- Is it technically feasible for Indonesia to take a pathway to the deep decarbonization of its energy system, taking into account the country's socioeconomic conditions, development aspirations, infrastructure stock, resource endowments, and other relevant factors?
- What investment would be required to achieve such a deep decarbonization?

Almost one half of Indonesia's GHG emissions come from land use, land use change and forestry (LULUCF). The second largest contributor of GHG emissions is energy-related activities (Table a) . Between 2000-2012, the energy sector's emissions grew at a rate of 4.5% annually, faster than the emissions growth rate of LULUCF, at 2.7%. This was the outcome of the rapid growth in energy consumption, along with better monitoring of the LULUCF sector. Rising energy consumption is a trend that will continue in Indonesia. Unless it is mitigated, GHG emissions from the energy sector will also continue to grow, demonstrating the crucial role of the energy sector in the decarbonization of Indonesia, which will be the focus of the remainder of this report.

Table a. Development of Indonesia GHG emission

Sectors	Million Ton CO_2-eq.		Percentage		Average annual growth
	2000	2012	2000	2012	
Energy	298	508	29.8	34.9	4.5%
IPPU	41	41	4.1	2.8	0.1%
Agriculture	96	113	9.6	7.8	1.3%
LULUCF*	505	695	50.5	47.8	2.7%
Waste	61	97	6.0	6.7	4.0%
Total	1,001	1,454			3.2%

* Including peat fire

1 Indonesia First Biennial Update Report

2 A study of the decarbonization of the forest sector is currently being prepared and will be published separately.

Methodology

The energy and GHG emission scenarios of DDPP were calculated using the calculator tool developed by the DDPP Secretariat (available at www.deepdecarbonization.org). The elaboration of the Indonesian DDPP scenarios has been conducted through an iterative process involving extensive consultation with domestic stakeholders in the areas of energy and climate change mitigation. The DDPP has been discussed in several national workshops and meetings such as workshop in the Indonesia University of Defense, SDSN Regional Workshop in Jakarta, Green Economy Workshop in Bandung coordinated by the Coordinating Minister of Economy. A crucial concern for domestic stakeholders regarding deep decarbonization emerged clearly from those workshops: the cost of implementation, and the potential negative effects on the country's economy.

The Scenarios

Three deep decarbonization pathways for Indonesia are defined in this study, all leading to comparable energy-related emission reduction but with different options for the transformation. The "Renewable Scenario" puts the emphasis on the large-scale deployment of renewable-based power generation complemented by nuclear energy. The "Renewable + CCS (Carbon Capture and Storage) Scenario" considers a more balanced technological deployment in power generation, in which renewables would still play an important role but be complemented by the diffusion of CCS and nuclear power. This scenario may be considered the back-up option if resource or technology constraints limit the deployment of renewables in the energy system. In the "Renewable" and "Renewable+CCS" scenarios, the assumed values for demand-related parameters are identical. Finally, the "Economic Structural Change Scenario" considers the role of structural changes in the Indonesian economy, with the implementation of a more service-oriented economy, combined with more energy efficiency measures, and more fuel switching to low- or non-carbon energy by end-users. In all three scenarios, the macroeconomic drivers are identical: economic growth 5.3% - 5.8% per year and population growth 1.15% per year in the near term and slowing down to 0.3% per year in the longer term.

Decarbonization Drivers and the Resulted CO_2 Emission

The Indonesian deep decarbonization pathways combine strong action on the three pillars–(i) energy efficiency and conservation, (ii) decarbonization of energy carriers, especially deep decarbonization of electricity generation, and (iii) fuel switching to low-and zero-carbon emitting energies, including substituting combustion energy system with electricity energy system (electrification of end use).

The three decarbonization scenarios reach the same level of energy-related emissions in 2050 i.e. 402 million tons of CO_2 (Figure a), corresponding to a decrease in terms of per capita emission, from 1.8 ton CO_2 in 2010 to 1.3 ton CO_2 in 2050. The emission profile over time is similar in all cases, with an increase over the 2010-2030 period in parallel with fast economic development, and then a decrease after 2030 when decarbonization measures are implemented at full scale.

Investments

Decarbonization requires investing specifically in low-carbon options, notably low- or zero-carbon emitting power plants, low- or zero-carbon fuel production units, and the procurement of low- or zero-carbon emitting vehicles (Figure b).[3] To put these numbers in perspective, we assess them as a share of GDP. Investments in low-carbon options for these three key activities correspond to a maximum of 1.22% of GDP in 2020, before decreasing gradually towards 0.54% in 2050. This means that these investments,

3 Several caveats must be noted for these assessments. First, the investment needs presented in this section do not include the additional infrastructure needed to support the operation of plants such as construction for gas pipelines, regasification plant (imported LNG), and to support the operation of electric vehicles or CNG such as recharging/refueling stations. Second, the costs associated with energy efficiency measures in buildings and industry have not been included.

although not negligible, are perfectly manageable for the Indonesian economy. This is even truer if we compare these investment needs with the total macroeconomic investment in Indonesia, which has been rising from 22% of GDP in the early-2000s to about 35% of GDP in early-2010s (World Bank data). Even if one assumes that gross capital formation reverts to the lower end of the range, investment in low-carbon options would still represent less than 5% of total investments in the Indonesian economy. Additionally, it must be noted that investments in low-carbon technologies under deep decarbonization happen in parallel with a significant reduction of fossil production (for both domestic uses and exports), triggering, in turn, a reduction of investments in the fossil-fuel sectors.

Figure a. CO_2 emission development scenarios

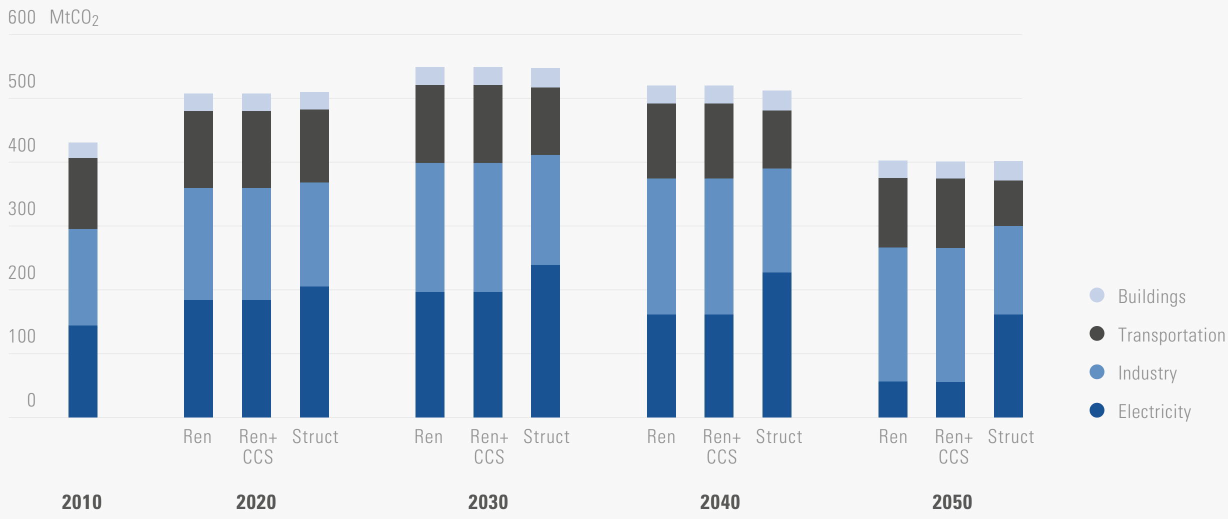
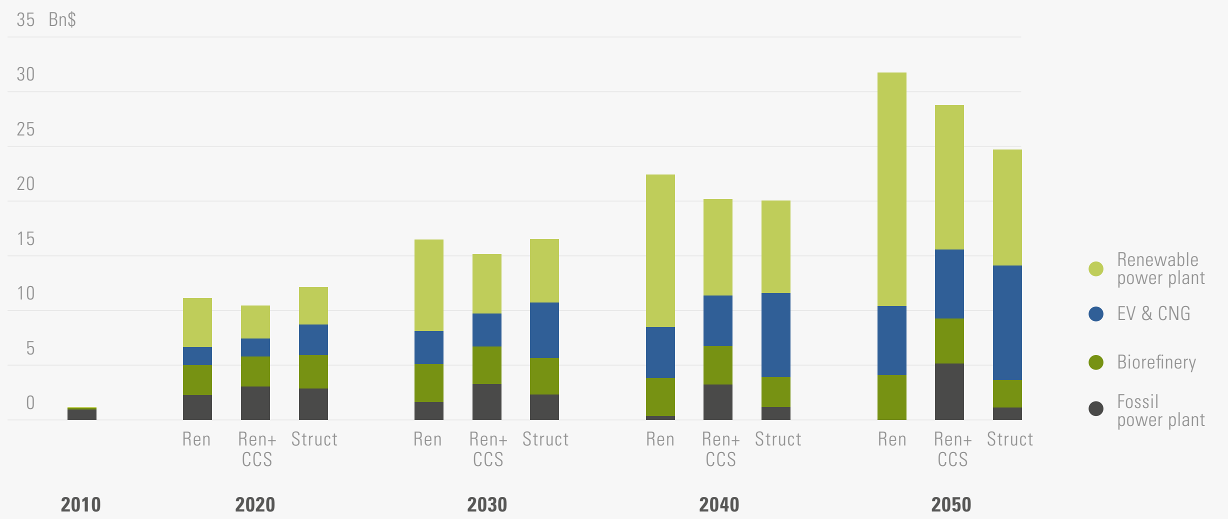


Figure b. Investment needed for capacity addition of power plant and reneries and for vehicle procurement



Key Messages

1. This study finds that Indonesia has the technical potential to deeply reduce its energy related CO_2 emission, to a level that will significantly contribute to the global efforts to prevent 2°C temperature increases in 2050. The three decarbonization scenarios envisaged in this study ("Renewable," "Renewable+CCS," and "Economic Structural Change") will all achieve about the same CO_2 emission level of 402 million tons in 2050, which in per capita terms translates to 1.3 ton CO_2/capita.

2. "Renewable," "Renewable+CCS," and "Economic Structural Change" scenarios all show that decarbonization could be technically achieved through the implementation of three decarbonization pillars: energy efficiency measures, electrification of end-use, and decarbonization of the electricity sector.

3. In line with, and to support the projected economic growth of between 5.4% - 5.8% per year, emissions will continue to increase in the 2010-2030 period (due to economic development), and then decrease afterwards (as a result of decarbonization measures). It is crucial to note, however, that the decrease of emissions in the long-term does not mean delaying action, but rather suggests following a streamlined, gradual development of low-carbon options in the short-term. This is crucial both to make available adequate infrastructure in due time, but also to avoid carbon lock-in if carbon-intensive infrastructure and technologies are installed over the next decade

4. The "Renewable" scenario assumes the total deployment of renewable energy (solar, hydro, geothermal) to replace most, if not all, fossil-fueled power plants. In addition to renewables, some fraction of the power plants would be nuclear-powered. This scenario assumes that large size solar PV are deployable, and that large hydro resources in Papua (eastern Indonesia) is utilizable, to cater demand in the western part of Indonesia through long distance sub-sea cables. In case long distance sub-sea cable technology is not yet deployable, decarbonization to 1.3 ton CO_2/capita is still achievable by combining renewables and fossil power plants equipped with CCS. The "Renewable+CCS" scenario is a back-up scenario for the "Renewable" scenario. I.e., if a sub-sea cable cannot be deployed, there is an alternative scheme to achieve the same decarbonization target.

5. Another alternative decarbonization pathway is transforming the country's economy towards a less energy-intensive one, i.e. through structural change towards more service- oriented industries. The "Economic Structural Change" scenario will result in lower energy demand, and combined with the three decarbonization pillars and deployment of renewables, make the decarbonization target more achievable than the first two scenarios.

6. Deep decarbonization requires an enormous amount of investment to build infrastructure and deploy lower-carbon-emitting technologies which are, in general, more expensive than conventional technologies. For Indonesia, where climate-change mitigation does not yet greatly concern the government or society in general, this large investment required for decarbonization is a major challenge. However, these investment needs still represent only a small fraction of total investments throughout the economy, especially in the context of the country's fast economic growth, which is assumed in our scenarios. The main challenge, therefore, is to develop adequate schemes and policy incentives to re-orient investments towards low-carbon options. This must include investing in infrastructure for deployment at scale, and in due time.

1 Introduction

This report presents the results of a deep decarbonization analysis conducted by the Indonesian Country Research Team consisting of researchers from Institut Teknologi Bandung, particularly the Center for Research on Energy Policy–Institut Teknologi Bandung and Centre for Climate Risk and Opportunity Management–Bogor Agriculture University. Our objective is to explore potential development pathways by which the Republic of Indonesia could achieve the deep decarbonization of its economy, to the level where it would contribute to the worldwide endeavor of limiting global temperature increases to less than 2°C.

At the current stage, our research is limited to exploring technical choices facing Indonesia, and their corresponding investment costs. The report also explores the crucial role of the energy sector in the decarbonization of Indonesia. The research addresses two main questions:

- Is it technically feasible for Indonesia to take a pathway to the deep decarbonization of its energy system, taking into account the country's socioeconomic conditions, development aspirations, infrastructure stock, resource endowments, and other relevant factors?
- What investment would be required to achieve such a deep decarbonization?

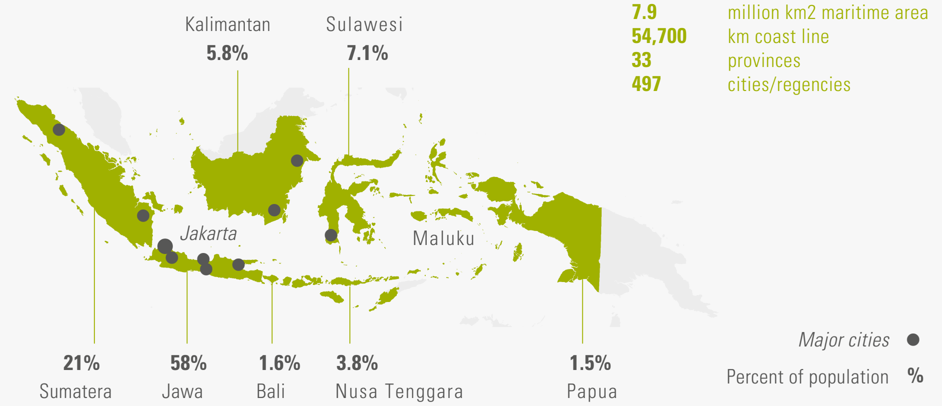
2 National Circumstances

2.1 Socioeconomic Conditions

The Republic of Indonesia is the largest archipelago in the world, consisting of approximately 17,000 islands. The majority of Indonesia's population, almost 80%, lives in the Western part of Indonesia, on the islands of Jawa and Sumatera (Java and Sumatra). In 2010, almost 60% of the population was living on Jawa. (See Figure 1).

Figure 1. Map of Indonesia with basic statistics

1.9	milliom km2 land area
7.9	million km2 maritime area
54,700	km coast line
33	provinces
497	cities/regencies



Indonesia encompasses 2 million km^2 of land territory. Of this land, about 0.5million km^2 are used for various agricultural activities. There is nearly 0.2 million km^2 of arable land, of which about 40% is wetland (e.g., rice fields), 40% is dry land, and 15% is shifting cultivation.

Indonesia is the world's fourth most populous country, with a population projected to exceed 300 million by 2030. During the past four decades, Indonesia's population has continuously increased, from 119 million (1971) to 237 million (2010). The rate of annual population growth, however, has gradually decreased, from 1.98% per year (1980-1990) to 1.49% (2000-2010) [1].

The islands of Java and Sumatera, where the population is concentrated, account for most of the country's economic activity. About half of the Indonesian population lives in urban areas. According to the most recent *World Urbanization Prospects* (UN Department of Economic and Social Affairs, Population Division), Indonesia's urban areas are expected to add 50 million people by 2050.

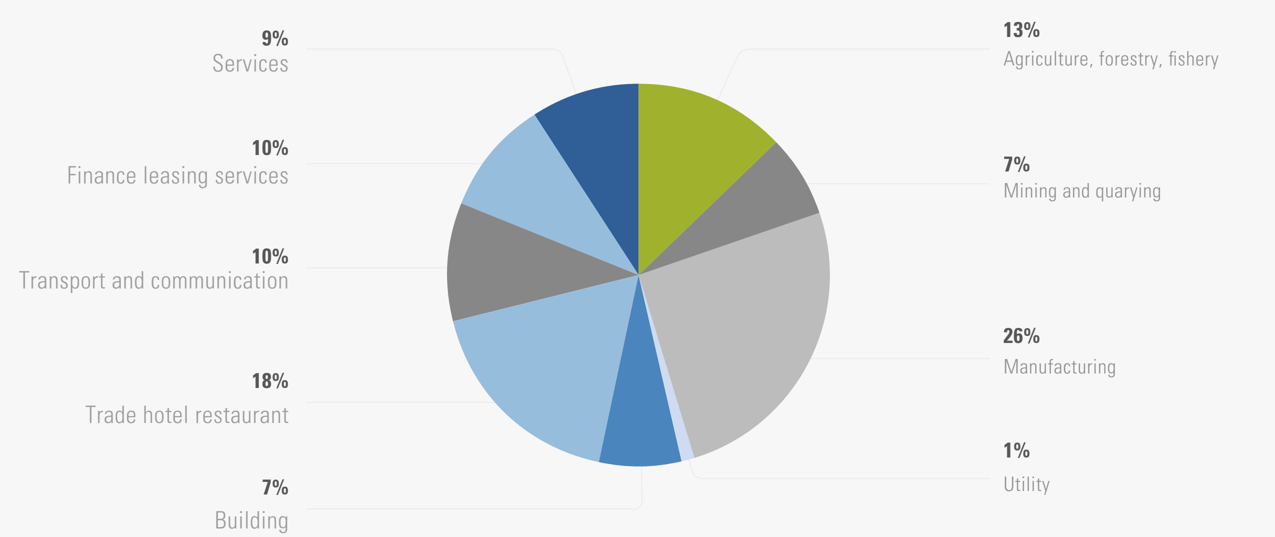
Indonesia has seen rapid economic growth during the last decade: its GDP has quadrupled from 2,300 trillion IDR (USD 248 billion) in 2004 to 10,543 trillion IDR (USD 888 billion) in 2014. This corresponds approximately to a tripling of GDP per capita, from IDR 10.5 million (USD 1,132) in 2004 to IDR 41.8 million (USD 3,632) in 2014. Indonesia's annual economic growth rate has averaged 5.7% per year. Indonesia's National Medium-Term Development Plan[2] set an annual economic growth target of 6% - 8% for the five years through 2019.

Over the past five decades, Indonesia's economy has experienced a structural transformation from an agricultural to an industrial and services economy. Agriculture represented just 15% of GDP in 2012, down from 54% in 1960. Figure 2 details the components Indonesia's GDP as of 2012.

In the last decade, the fastest average rates of expansion have occurred in the transport and communication sectors (12.4% growth per year), followed by utilities (7.5% growth per year), and the finance and leasing services sector (6.8% growth per year).

1 BPS-Statistics of Indonesia 2010
2 RPJMN 2015-2019

Figure 2. The Indonesian economy (2012)



Indonesia's unemployment and underemployment rates have decreased during the last decade, from about 10% (2004) to about 6% (2013).[3] Yet poverty remains a challenge for Indonesia. The poverty rate fell for several decades from 1970, when 70 million people (60% of the population) were living below the poverty line. This dropped to 27 million people below the poverty line in 1990, and fewer than 20 million people in 1997. The trend reversed, however, in the aftermath of the 1998 Asian monetary crisis. Despite a successful recovery, and economic and political reforms undertaken since 2000, about 27.7 million people (11% of the population) were considered poor, by the government's measures, in 2014.[4]

According to the National Medium-Term Development Plan (RPJMN 2015-2019), the government intends to implement various development and welfare programs, to reduce by 2019 the percentage of the population living in poverty from today's 11% to 6.5% - 8.0%. These welfare programs are to include social assistance, community development, and the empowerment of micro- and small enterprises. Social conditions have improved considerably in the last four decades. Median life expectancy at birth in Indonesia has risen from just 47.9 years (1970) to 69.7 years (2011). According to Central Bureau of Statistics (BPS) projections, life expectancy is set to reach 70.1 years in 2015. These gains in longevity are a consequence of rising incomes, as well as the government's provision of various health programs.[5] Sustained public efforts in the education sector have also achieved significant successes. Adult literacy has risen from 79% (1970) to 95% (2011).

2.2 Past and Current Trends in Energy Supply and Demand

Indonesia is endowed with an abundance and a variety of energy resources. (Table 1.) Historically, oil was Indonesia's most important energy resource, and oil was the predominant fuel, accounting for most domestic energy consumption. Oil, together with natural gas, were the main export revenue of the country. In its peak in 1981 and 1982 oil and gas export accounted 82% of total export. Due to fast growing non oil & gas export value and stagnant oil and gas export, since 1987 share of non-oil & gas in total export has been higher than that of oil & gas.

Table 1. Indonesia's energy resources, 2012

Energy Resource	Reserve	Resource
Oil, billion barrels	7.4	
Natural Gas, TSCF	150	
Coal, billion ton	28	119
CBM, TSCF		453
Shale Gas, TSCF		574
	Potential	
Hydro	75,000 MW	
Geothermal	29,000 MW	
Micro-hydro	750 MW	
Biomass	14,000 MWe	
Solar	4,80 kWh/m^2 /day	
Wind	3 – 6 m/second	

3 According to the definition of Central Bureau of Statistics (BPS), the type of employment includes all kind of jobs (activity to earn income), including informal sector, low-skilled, and ill-paid jobs; an individual is considered employed when she/he worked to earn income at least one hour last week.

4 It should be noted that the Government of Indonesia (GOI) defines poverty line using country-specific measures; in 2014 the poverty line is monthly per capita income of 300,000 IDR (approximately $25), which is very low standard of living when referring to World Bank poverty definition i.e. those lives on or below $ 2 per day (moderate poverty). If the World Bank definition is applied in Indonesia case, then the poverty rate in Indonesia is higher than that cited above.

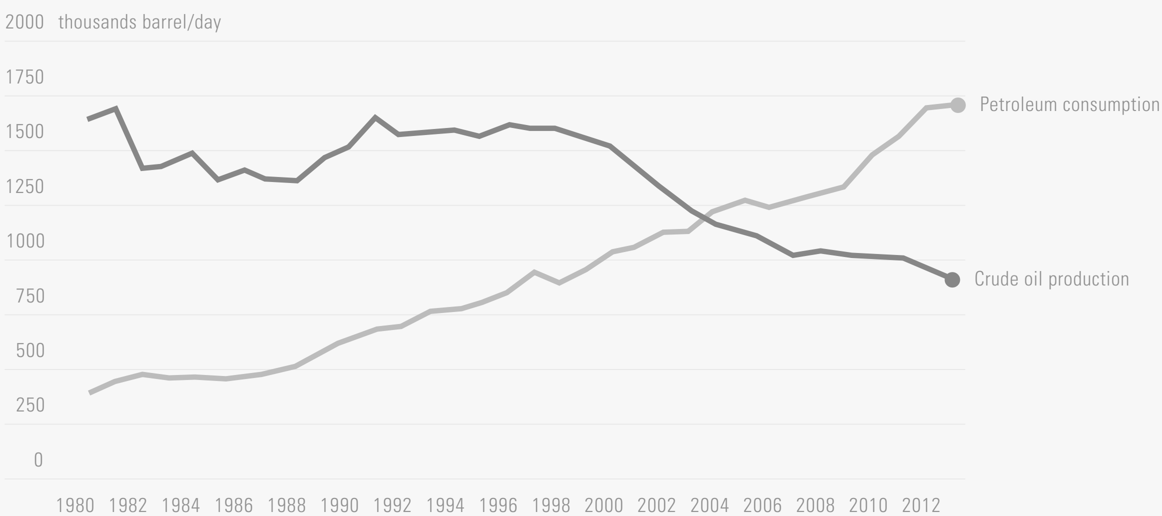
5 Examples include the development of community-level primary health centers since the 1970s, and since the 1990s, the mandatory deployment of young doctors to work for two to three years in rural areas.

Currently the share of oil and gas export has decreased to only around 19% of total export. Until 2004, Indonesia was a net oil exporter; it was a member of OPEC from 1962 to 2009. However, demand for energy grew in the 1980s and 1990s due to the country's rising population and rapid economic growth. Those factors, along with decreasing reserves,[6] turned Indonesia into a net oil importer beginning in 2004. (Figure 3)

Natural gas also plays an important role in meeting domestic energy demand. Indonesian gas production began in the 1970s and today generates considerable export revenue. Natural gas production reached 60 BCM in 1990 and 90 BCM in 2012,[7] primarily in the form of liquefied natural gas (LNG) for export, and as piped gas to Singapore beginning in 2002. However, what began mainly as an export has shifted since 2000, in tandem with a decline in Indonesia's oil reserves and petroleum production since 2000. Those declines led the government to divert gas from export to the domestic market. At publication time, 45% of gas production was exported; 40% was directed to domestic uses (electricity generation, industry, and city gas); 15% is used for oil and gas field operation, including gas flaring . Current Indonesian gas policy aims to further divert LNG from the export market towards meeting growing domestic demand for gas.

In addition to oil and gas, Indonesia is also endowed with around 28 billion ton coal reserves (rank number 10 in the world reserves). Indonesia is one of the world's largest thermal coal exporters today, primarily exporting to China and India. Indonesia coal production began in the 1980s, mainly to meet domestic demand

Figure 3. Indonesian petroleum consumption and crude oil production



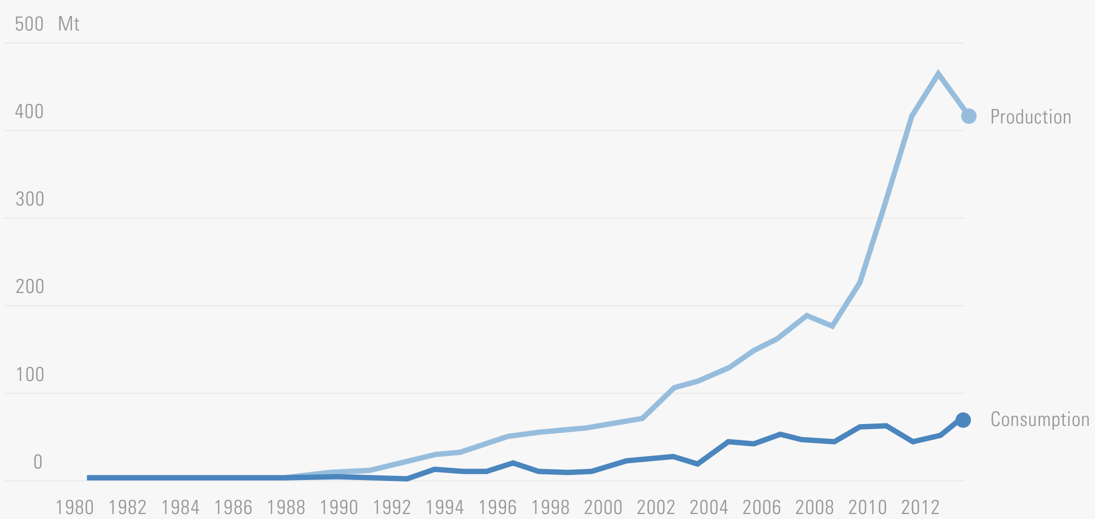
6 Indonesian petroleum exploration and development has long taken place in the western part of the country, which is a relatively easy frontier of mostly onshore or shallow water fields. The fields in this area began to decline in the late-1990s. Exploration in eastern Indonesia is limited due to a lack of incentives for exploring a difficult frontier (deep water, limited infrastructure to support exploration). The discovery rate from exploration is relatively low compared to the rate of exploitation, resulting in diminishing reserves.

7 In 2012, Indonesia's annual gas production was approximately 90 BCM (566 million BOE), larger than the country's crude oil and condensate production (315 million barrels in 2012).

from power plants and industry. Coal production has been steadily increasing since the 1990s (Figure 4) when the government opened coal concessions to foreign investment. Since then, coal production has become export-oriented. Indonesian coal is medium-ranked coal[8] and low-ranked coal.[9] Export revenues from coal play an important role in the Indonesian economy, accounting today for about 15% of total export revenues, approaching the revenue generated by gas exports. The Indonesian economy's dependence on coal export revenue could be clearly observed in 2013 and 2014 when China cut its coal imports from Indonesia by about 50%. Ripple effects included the weakening of the Indonesian rupiah (IDR), amid a shortage of hard currency needed for various imports (oil, industry capital goods, and consumer goods). Indonesia's heavy reliance on commodity exports, including coal, has become economically unsustainable, as the economy is vulnerable to external shocks and volatility. Indonesia needs to move towards less susceptibility to external shocks, such as by shifting the country towards a service-oriented economy.

Indonesia also has various renewable energy resources (Table 1). Currently the country's renewable energy resources that have been utilized are hydropower, geothermal and biofuel. In 2013, hydropower and geothermal combined accounted 25% of total power generation. Indonesia's biofuel production reached 2.8 million kilo liters (17.6 million barrels) in 2013. Around 36% of the production (1 million kilo liters) was for domestic market while the remaining 64% was for export. The biodiesel consumption is very tiny (1.3%) compared to oil fuels consumption. Until recently, subsidies on oil fuels and electricity prevented renewable resources from being a competitive option, so their utilization was limited. This changed in early 2015 when the government removed around 80% of these energy subsidies (and redirected the subsidy budget into social programs such as health and education

Figure 4. Indonesian coal production and consumption



8 Calorific value between 5100 and 6100 kcal/kg

9 Calorific value below 5100 kcal/kg

services, and subsistence food aid for the poor and infrastructure investment)[10]. The removal of subsidy, which will make renewable energy become cost competitive to fossil energy, is expected to encourage more development of the country's renewable energy resources.

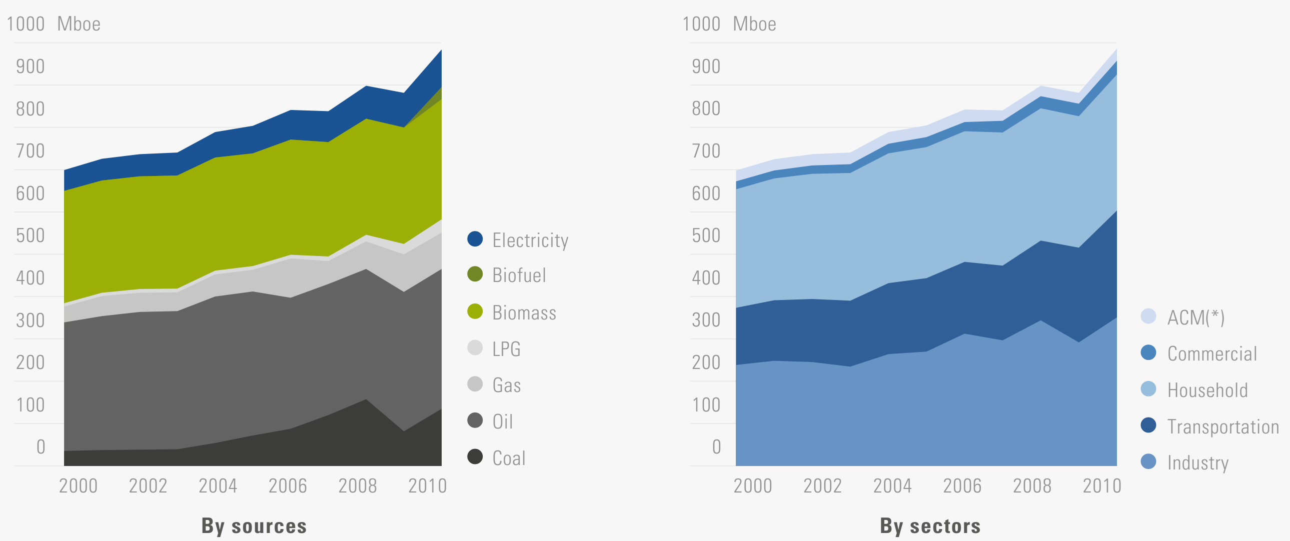
Thanks to the sale of natural resources to domestic and exports markets, the energy sector generates government revenues, royalties, and taxes. The recent removal of a large energy subsidy will enable the government to use more of these revenues to finance the public infrastructure investment needed to boost economic development.

Between 2000 and 2010, primary energy supply grew at a rate of 3.7% per year, from 996 million to 1431 million BOE (Figure 5a). The primary energy supply remains dominated by oil, followed by coal and natural gas. Ever since the decline in domestic oil production capacity, the government has attempted to move the country away from oil, to ensure national energy security, by promoting energy sources abundantly available in the country, i.e. coal, natural gas, and renewable energy. These attempts have resulted in a high growth rate in coal supply (11.5% per year), far outstripping the growth of the oil (2.8% per year) and natural gas supply (3.9% per year). In the decade ending in 2010, the share of oil in the supply mix has shrunk from 41% (2000) to 36% (2010). Meanwhile, coal's share has doubled from 9% (2000) to 20% (2010).

Final energy consumption has been growing in line with economic and population growth, at an average annual rate of 3.5% (2000-2010), from 709 million to 998 million BOE. However, it is worth noting that the rate of growth of energy consumption is lower than the rate of economic growth during the same period (5.5% per year). This indicates that a decoupling of energy use and economic development is well underway.

The industrial, residential, and transport sectors

Figure 5. Indonesian final energy demand



10 Currently, the only energy subsidies that remain are on liquefied petroleum gas (LPG) for the poor, kerosene for households in eastern Indonesia that do not have access to LPG, and electricity for small scale residential customers (tariff category 450 VA) and buildings for social non-profit activities (orphan housing, state-owned medical centers, state-owned student housing, rehabilitation centers, mosques, churches etc.).

dominate final energy consumption (Figure 5b), with notably high annual growth in consumption in the transport sector (6.4% per year). Brisk growth in transport sector consumption is a consequence of economic growth, relatively cheap oil fuel at subsidized prices, and the rapid rise in personal vehicle ownership, especially motorcycles, due to easy access to credit. Demand for energy grew, on average, by 3.9% in the industrial sector, and by 1.7% in the building (residential and commercial) sector. The energy demand growth rate of industrial sector is slightly lower than GDP growth of industrial sector for the same period (4.5% per year), an indication that industry is becoming more energy efficient, and that Indonesia is moving toward less energy-intensive industries.

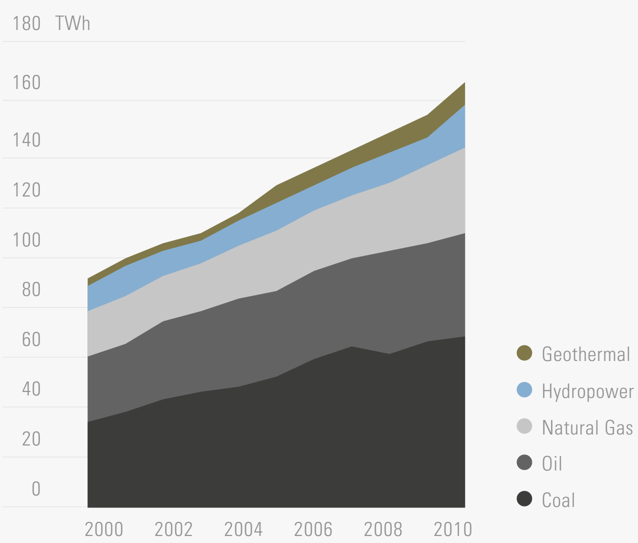
Energy demand is still dominated by oil, which accounts for about 37% of total consumption; followed by biomass (26.1%), used primarily in rural residences; gas (15.6%); coal (11.4%); and electricity (9.9%), essentially used in the industry and building sectos. The growth in demand for gas was high during 2000-2010 due to a change in government policy (a subsidy on kerosene for the residential sector was discontinued and a subsidy on LPG took its place). Coal as a final energy occurred solely in the industrial sector. Rising demand for coal occurred due to the removal of a subsidy on industrial diesel, leading many industries to switch from diesel to coal.

About 10% of final energy consumption took the form of electricity. Buildings, both residential and commercial, accounted for 65% of consumption; the remaining 35% was used for industrial activities. Coal, gas, hydropower, geothermal, and oil fuels are the main sources in the power generation mix (Figure 6). Electricity production has grown. Notably, most of the increase in electricity production over the last decade has come thanks to a steady rise in coal-based power generation, which has experienced a 7.3% annual increase over the period. It grew to represent 41% of electricity production (2010), up from 37% (2000).

Gas power plants also grew in the past decade at a rate of 6.2% per year. The growth was an outcome of a government policy designed to move domestic consumers away from oil and to prioritize natural gas production, and also because of improvements in Indonesia's gas infrastructure. In 2010, gas power plants accounted for 20% of electricity generation, little changed from 2000. Meanwhile, despite the government effort to reduce oil consumption, electricity from oil-fueled power plants still grew by 4.6% per year. The oil-fueled power plants are small-to-medium sized diesel generation plants distributed across many remote regions of the country, installed as part of programs to boost rural electrification. The share of oil-fueled plants in the mix has decreased from 28% (2000) to 24% (2010).

Geothermal represents less than 5% of the power generation mix. Yet it has been the only power source experiencing double-digit annual growth over the last decade, highlighting the potential of geothermal energy in Indonesia.

Figure 6. Development of Indonesia's Power Generation Mix



2.3 The Future of the Indonesian Energy System: Current Approaches

The challenge facing Indonesia's energy sector as it evolves is to satisfy the nation's rapidly increasing demand for energy services, under conditions of fast economic development and rising living standards, is how to control the dynamics of the energy supply required, both in volume and in kind. National energy policy puts an emphasis on energy security and independence as core objectives. This, in turn, means that energy demand must be satisfied to the greatest extent possible with domestic resources. Current national energy policy, released by the Government of Indonesia (GOI) through the National Energy Council (DEN), provides guidance to the country's future energy development. Its three main features are:

- To strive for energy security and independence by moving away from oil, with the goal of reducing oil to 25% of supply in 2025, and promoting more abundant domestic resources such as natural gas and coal.
- To increase energy efficiency.
- To promote the development of renewable energy, with a target of renewables as 23% of the supply mix in 2025.

Under this policy framework, the National Energy Council released a long-term energy supply scenario that relies heavily on coal and other abundant domestic resources (Figure 7). One can see from the figure that, despite some growth in renewable energy, Indonesia's future energy supply still relies heavily on fossil fuels and is, therefore, far from a development pathway to deep decarbonization.

2.4 Current GHG Emissions

Almost one half of Indonesia's GHG emissions come from land use, land use change and forestry (LULUCF). The second largest contributor of GHG emissions is energy-related activities (Table 2)[11]. Between 2000-2012, the energy sector's emissions grew at a rate of 4.5% annually, faster than the emissions growth rate of

Figure 7. National Energy Council's energy supply scenario

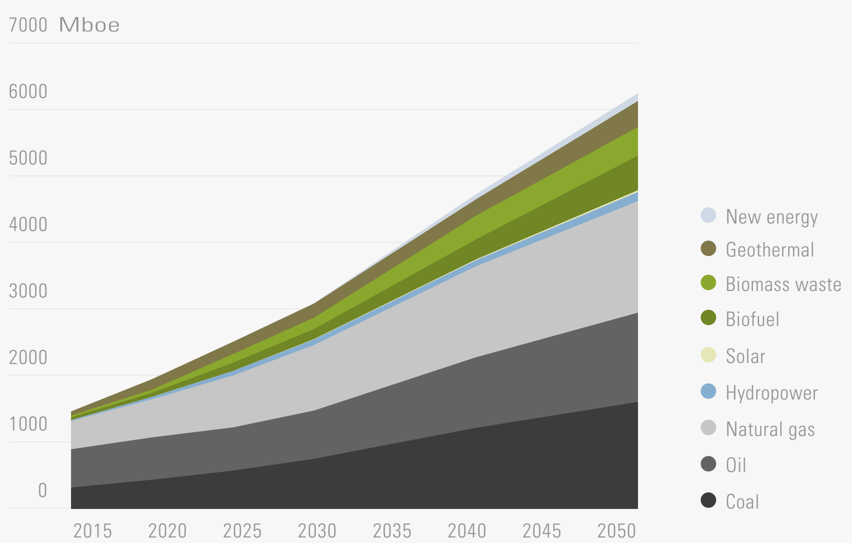


Table 2. Development of Indonesia GHG emission

Sectors	Million Ton CO_2-eq.		Percentage		Average annual growth
	2000	2012	2000	2012	
Energy	298	508	29.8	34.9	4.5%
IPPU	41	41	4.1	2.8	0.1%
Agriculture	96	113	9.6	7.8	1.3%
LULUCF*	505	695	50.5	47.8	2.7%
Waste	61	97	6.0	6.7	4.0%
Total	1,001	1,454			3.2%

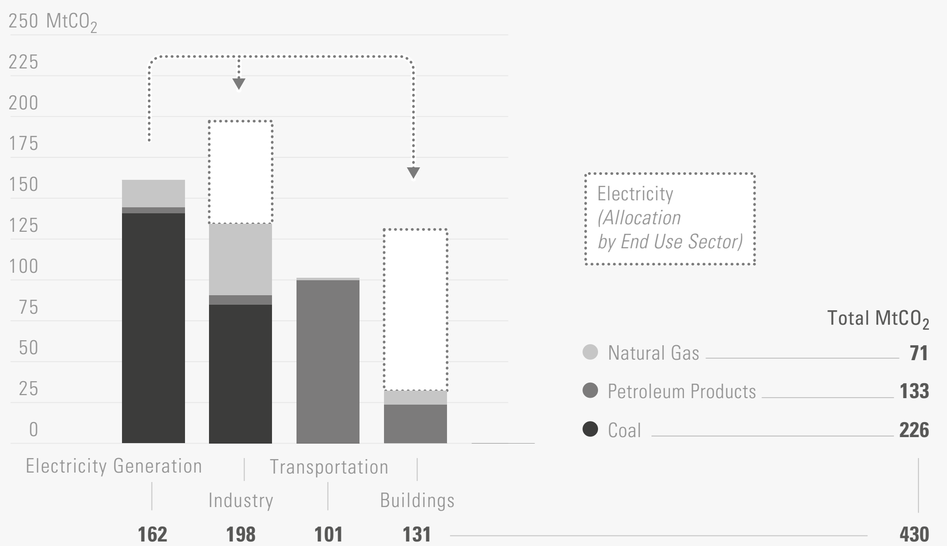
* Including peat fire

LULUCF, at 2.7%. This was the outcome of the rapid growth in energy consumption, along with better monitoring of the LULUCF sector.

Rising energy consumption is a trend that will continue in Indonesia. Unless it is mitigated, GHG emissions from the energy sector will also continue to grow, demonstrating the crucial role of the energy sector in the decarbonization of Indonesia, which will be the focus of the remainder of this report.[12]

In the energy sector, coal is notably the major source of energy-related emissions, given its role as the main fuel in power generation and industry (Figure 8). Oil is used in the transport and building sectors; gas is used essentially in the industrial sector; emissions from power generation are accounted for by the buildings (commercial and residential) sector (60%) and industry (40%).

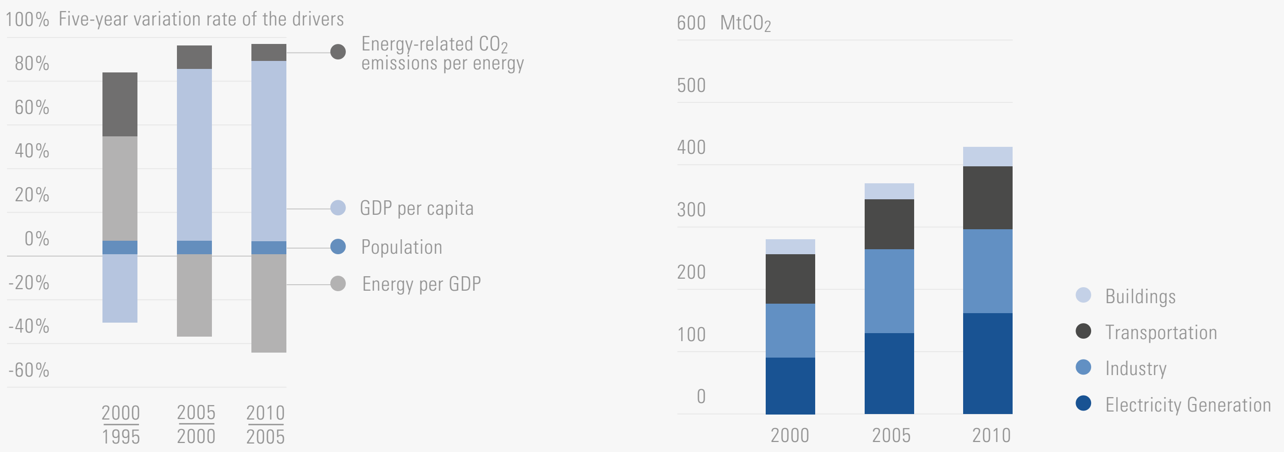
Figure 8. Fossil Fuel Combustion CO_2 Emissions in 2010



11 Indonesia First Biennial Update Report

12 A study of the decarbonization of the forest sector is currently being prepared and will be published separately.

Figure 9. Decomposition of historical energy-related CO_2 emissions, 2000-2010



Considering the decomposition of energy-related emissions (Figure 9), the main driver of energy-related CO_2 emissions over the past decade has been economic activity, which grew at an annual rate of 5% to 6%. A small increase in the carbon intensity of energy can also be observed, triggered by the growing importance of coal (as it was substituted for oil, which is less carbon-intensive). On the other hand, the Indonesian economy has experienced important improvements in energy efficiency, as captured by the steady decrease in the energy use per GDP.

2.5 Deep Decarbonization Pathways Project (DDPP) and its relevance to Indonesia

Indonesia is among the countries that will be most affected by climate change. While climate variability and trends differ vastly across the region and between seasons, according to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC), the observed and projected evidence of climate change in Southeast Asia, including Indonesia, are:

- Annual total wet-day rainfall has increased by 22 mm per decade, while rainfall from extreme rain days has increased by 10 mm per decade
- Between 1955 and 2005, the ratio of rainfall in the wet to the dry seasons increased
- An increased frequency of extreme events has been reported in northern Southeast Asia[13]
- Rainfall intensity increased in much of the region[14]. Future increases in precipitation extremes related to the monsoon are very likely in East, South, and Southeast Asia.
- The projected detrimental impacts of climate change include droughts, forest fires, smoke aerosols, and the vulnerability of livelihoods in agrarian communities[15]

13 A decrease in such events has been reported in Myanmar

14 In Peninsular Malaya during the southwest monsoon season, total rainfall and the frequency of wet days decreased, but during the northeast monsoon, total rainfall, the frequency of extreme rainfall events, and rainfall intensity all increased over the peninsula.

15 Vulnerability of agrarian communities also arises from their geographic settings, demographic trends, socioeconomic factors, access to resources and markets, unsustainable water consumption, farming practices, and lack of adaptive capacity.

Meanwhile, Indonesia is among the largest GHG emitter. Therefore, it is reasonable and appropriate to expect that Indonesia will actively contribute to the global effort to prevent a 2oC increase in global temperatures by 2050 through the decarbonization of its economy.

- The deep decarbonization of Indonesia's economy may have additional benefits for the country besides mitigating the impact of climate change. These may include:

Reduced local pollution due to changes in transport, industry, power plants, and residential buildings.

- Economic stimulation as a consequence of developing new, lower-carbon emitting technologies.
- Energy efficiency increasing the economy's productivity.
- Improved energy security through realizing the potential of domestic renewable-energy sources, which are among the largest in the world.
- Jobs creation from renewable energy development, such as plantation work for producing biofuel feedstock.

3 Methodology

The Indonesian DDPP report was prepared by a team consisting of researchers from Institut Teknologi Bandung, particularly the Center for Research on Energy Policy – Institut Teknologi Bandung and Centre for Climate Risk and Opportunity Management-Bogor Agriculture University. The energy and GHG emission scenarios of DDPP were calculated using the calculator tool developed by the DDPP Secretariat (available at www.deepdecarbonization.org).

The elaboration of the Indonesian DDPP scenarios has been conducted through an iterative process involving extensive consultation with domestic stakeholders in the areas of energy and climate change mitigation. The DDPP has been discussed in several national workshops and meetings such as workshop in the Indonesia University of Defense, SDSN Regional Workshop in Jakarta, Green Economy Workshop in Bandung coordinated by the Coordinating Minister of Economy. A crucial concern for domestic stakeholders regarding deep decarbonization emerged clearly from those workshops: the cost of implementation, and the potential negative effects on the country's economy. The outcome of those concerns is that Indonesian stakeholders approach the issue of deep decarbonization as a negotiation, specifically one in which they seek to negotiate international financial support.

Acknowledging these legitimate concerns, this DDPP research seeks to bring forward a number of elements to structure discussions on ambition and equity, in line with the current conception of international climate negotiations framed around intended nationally determined contributions (INDCs), and a bottom-up approach, on the basis of two principles:

- Individual countries' ambition is driven by the radical transformation required to deliver successful decarbonization, not by a benchmark against other country's transformation effort. These transformations must be defined by each country individually, according to its specificities and domestic interests. The discussion of transformations required must make explicit and transparent the relation between short-term actions and their long-term effects on climate change.
- An in-depth investigation is needed into the content of these national transformations, to identify the collective mechanisms that may facilitate and enable them. We must identify the ambitious actions to be implemented, if we are to build a robust and resilient transi-

tion. We must likewise identify the challenges that national transformations will pose, which can be addressed by adequate international cooperation.

The analysis presented in this report is a scientific assessment that indicates the technical potential of Indonesia to reduce GHG emissions; it is not the Indonesian government's plan nor its commitment to climate change mitigation. Starting from the two principles above, this study investigates i) the transformations that can realistically be envisaged to move te Indonesian economy towards deep decarbonization, and ii) the investment needed to support this transformation, and iii) the challenges, opportunities and enabling conditions associated with these transformations.

4 Scenarios

Three deep decarbonization pathways for Indonesia are defined in this study, all leading to comparable energy-related emission reduction but with different options for the transformation. The "Renewable Scenario" puts the emphasis on the large-scale deployment of renewable-based power generation complemented by nuclear energy. The "Renewable + CCS (Carbon Capture and Storage) Scenario" considers a more balanced technological deployment in power generation, in which renewables would still play an important role but be complemented by the diffusion of CCS and nuclear power. This scenario may be considered the back-up option if resource or technology constraints limit the deployment of renewables in the energy system. In the "Renewable" and "Renewable+CCS" scenarios, the assumed values for demand-related parameters are identical. Finally, the "Economic Structural Change Scenario" considers the role of structural changes in the Indonesian economy, with the implementation of a more service-oriented economy, combined with more energy efficiency measures, and more fuel switching to low- or non-carbon energy by end-users. This last scenario, which targets decarbonization by focusing on the demand side, may be considered an alternative to the other two scenarios whose core deep decarbonization transformation concerns the supply side. In all three scenarios, the decarbonization of end-users is assumed. This means, for example, measures to improve equipment efficiency, a switch of fuels to biofuel and natural gas in transport, the deployment of electric vehicles, and a shift in the predominant mode of transport from personal vehicles to mass transport. The different assumptions made in the three scenarios are shown in Table 3. In the "Renewable" and "Renewable+CCS" scenarios, the demand parameters are identical. In the "Economic Structural Change Scenario," because the economy is more service-oriented, industry's contribution to GDP is assumed to decrease from 28% in 2010 to 12% in 2050. This is a larger change in economic structure than that assumed in the supply-side scenarios, where the share of industrial GDP is assumed to decrease from 28% in 2010 to 18% in 2050. In all three scenarios, the macroeconomic drivers and crucial development indicators are identical (Table 4).

Indonesia is a developing country, where the economy and population are projected to grow significantly in the next four decades. The scenarios assume a rate of increase in GDP per capita at a rather constant 4.8% throughout the 2010-2050 period, consistent with development needs. In parallel, the scenarios assume the growth of the Indonesian population at a rate of about 1.1% per year until 2020, and then 0.6% per year afterwards to reach 300 million

Table 3. Assumptions in the three scenarios

Sub-sector	Technology/fuel type and size	Unit	2010	Ren	Ren+CCS	Struct
				2050	2050	2050
Commerce	Commercial floor space	Bm^2	0.4	0.8	0.8	1.8
	Unit energy consumption	MJ/m^2	460	650	650	640
Car (Personal and Taxi)	Share of EV in VKMT	%	0%	20%	20%	40%
	Share of Ethanol in PKM	%	0%	20%	20%	40%
Bus	Share of Electric in VKM	%	0%	5%	5%	10%
	Share of Biodiesel in VKM	%	0%	30%	30%	50%
Urban Rail	Share of Electric in PKM	%	0%	10%	10%	20%
	Share of Biodiesel in PKM	%	0%	20%	20%	50%
Air	Share of Biofuel in PKM	%	0%	20%	20%	40%
Freight Transport & Pipelines	Total Ton-kilometers (TTKM)	TTKM	0.45	1.2	1.2	1.3
	Share of Rail in TTKM	%	3%	10%	10%	20%
Freight Trucks	Share of TKM -Biodiesel	%	0%	30%	30%	40%
	Share of TKM - CNG	%	0%	20%	20%	30%
Freight Rail	Share of Electric in TKM	%	0%	20%	20%	50%
	Share of Biodiesel in TKM	%	0%	20%	20%	40%
Industry	Industry share of GDP	%	28%	18%	18%	12%
Iron and Steel Manufacturing	Physical Output	Million tons/yr	3.5	12.0	12.0	10.0
Cement Manufacturing	Physical Output	Million tons/yr	37	100	100	80
Small/Medium Manufacturing	Energy intensity	MJ/$	23.0	18.0	18.0	15.0
Power Sector	Share of Coal	%	49%	2.0%	1%	9%
	Share of Coal w/ CCS	%	0%	0%	19%	0%
	Share of Fuel Oil	%	12%	1.0%	1%	1%
	Share of Natural gas	%	30%	7%	2%	22%
	Share of Natural gas w/ CCS	%	0%	0%	18%	0%
	Share of Nuclear	%	0.0%	16%	10%	10%
	Share of Hydropower	%	6%	20%	12%	11%
	Share of Wind-Offshore	%	0.0%	2%	1%	2%
	Share of Solar PV	%	0.0%	20%	15%	13%
	Share of Biomass	%	0.05%	12%	6.00%	10%
	Share of Geothermal	%	3.00%	18%	12%	20%
	Share of Biofuel	%	0.0%	2%	3%	2%

Table 4. Development Indicators and Energy Service Demand Drivers

	2010	2020	2030	2040	2050
Population [Millions]	234	252	271	289	307
GDP per capita [$/capita]	2,306	3,655	5,823	9,319	14,974
Electrification rate	70%	85%	99%	99%	99%
Poverty indicator	12%	8%	3%	3%	2%

people by 2050. This leads to a steady growth of total GDP between 5.4% and 5.8% annually throughout the period. In parallel, the deep decarbonization pathways are built on the assumptions that almost all households get access to electricity by 2050, and that the eradication of poverty accelerates steadily to ensure that only 2% households are left poor in 2050 (compared to 12% today). Under all three scenarios massive development of no or low carbon electricity infrastructure, which is the major component of decarbonization, will ensure that almost 100% of households achieve electrification. All scenarios also assume the development of the necessary gas infrastructure to enable the power-generation sector to switch fuel to gas, for distribution to industry and to households. The availability of electricity and gas to households will catalyze the creation of business activities and employment, including small- and medium-sized enterprises in suburban and rural areas. The scenarios assume that the development of plantations for biofuel feedstock will also create jobs in rural areas, in turn helping reduce urbanization of low-skill individuals, often a cause of poverty in big cities. The creation of businesses and jobs that would accompany decarbonization and be an outcome are in line with the country's development objective of eradicating poverty.

The outcomes of improved access to modern energy (electricity and gas), and the eradication of poverty, demonstrate that deep decarbonization is not envisaged in opposition to Indonesia's crucial development needs, but rather is conceived to ensure at once the parallel satisfaction of socioeconomic priorities and low-carbon transformation.

The crucial constraint that delineates the elaboration of scenarios in Indonesia is the availability of domestic renewable energy resources which can reasonably be expected to be deployed. Indeed, Indonesia has potentially very important renewable resources (see Section 2), which constitute the natural solution for implementing deep decarbonization. But the question is whether they can be developed in due time and at the necessary scale, if considering only commercial technologies or those that can be expected to be commercial in the near future. The availability in Indonesia of appropriate geological formation for CCS is another important dimension that defines whether the use of domestic fossil fuels (notably coal) can be compatible with the objective of deep decarbonization.

5 Decarbonization Strategy

Indonesia's deep decarbonization pathways are organized around a combination of common pillars that affect the whole energy system and must all be mobilized to a certain extent, but with different magnitudes and different modes of implementation, depending on the scenario considered:

- Energy efficiency, through the deployment of efficient technology on the demand and supply side.
- Fuel switching, through the deployment of low- and zero-carbon-emitting energy systems for final end-uses, to significantly decrease the use of coal and oil while increasing the share of natural gas and of electricity.
- Decarbonization of the power sector, through the deployment of low-carbon power generation options (renewables, CCS, nuclear).
- Structural changes in the economy towards less energy- and carbon-intensive activities (*i.e.* decreased role of industry in the formation of national GDP through service sector substitution).

5.1 Results: High-Level Summary

This section summarizes the high-level results of the analysis of the three scenarios. The summary includes comparison of values in 2010 and 2050 for final energy consumption, primary energy supply, emissions, and drivers of decarbonization.

Final Energy Demand

Indonesia's continuing economic growth and rising population lead to an increase in final energy demand (Figure 10). In the "Renewable Scenario" and "Renewable+CCS Scenario," the final energy demand in 2050 is 2.4 times higher than in 2010, corresponding to an average annual growth or about 2% in the period 2010-2050. It must be noted, however, that this growth is significantly lower than average annual GDP growth, which is in the range of 5.4%-5.8%, demonstrating a strong decoupling. Important changes from 2010 to 2050 include the significant increase in the share of electricity, gas, and biofuels in the energy mix, in parallel with a strong decrease in oil fuel and direct use of coal.

The "Economic Structural Change Scenario" has lower final energy demand in 2050 compared to the other scenarios, a logical consequence of the lower share of energy-intensive activities in national GDP, replaced by low-energy industry and service (tertiary) industry. This leads to a significantly lower level of final consumption of gas and oil compared to the two other scenarios, because these fuels are to a large extent required by industrial activities. Instead, electricity plays a more dominant role in the final energy mix. In the supply-side scenario, the share of electricity in final energy increased from 12% in 2010 to 34% in 2050. In the "Economic Structural Change" scenario, the electricity share is even higher: 37% in 2050.

Primary Energy Supply

In the "Renewables" scenario, primary energy in 2050 is doubled compared to 2010, indicating a 15% improvement in energy-conversion efficiency between primary and final energy (given that final energy is multiplied by 2.35 over the same period). This ratio is very similar in the "Structural

Figure 10. Final energy pathways, by type of energy

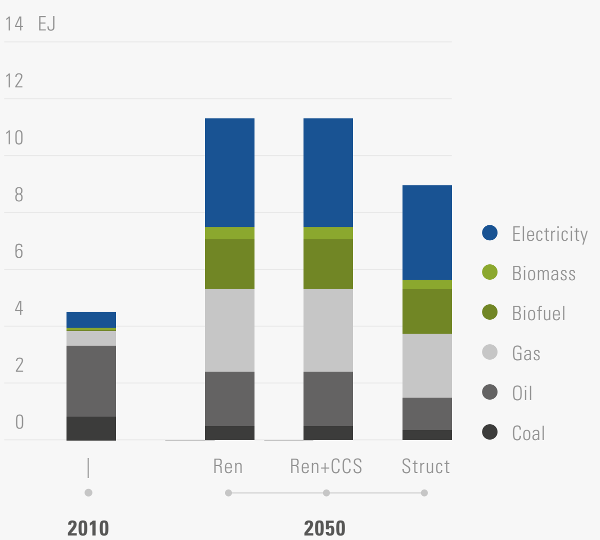
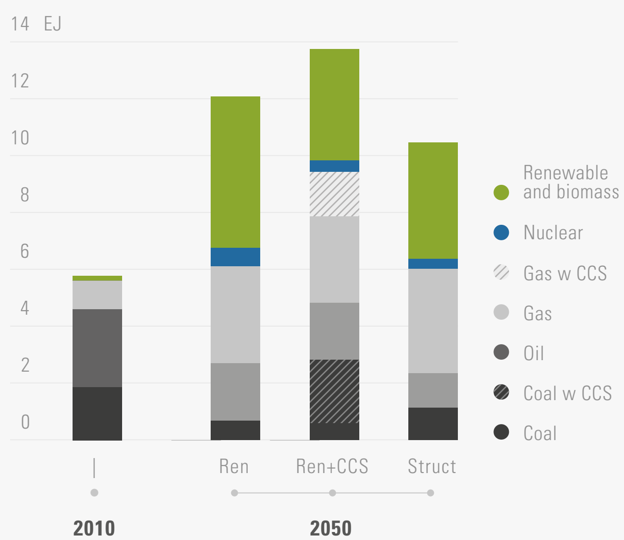


Figure 11. Pathway of Primary Energy, by source



Change" scenario. But the trend is notably different in the "Renewable+CCS Scenario," where primary energy increases almost proportionally with final energy. In this latter case, the diffusion of CCS leads to the lower efficiency of the full energy transformation process. Fossil-based power plants equipped with CSS has less transformation efficiency than renewable-based power plants (where it is assumed to be close to 100%). In particular, there is a significant rise in the use of fossil fuels (5 times higher than fossil energy usage in the "Renewable" scenario).

Decarbonization Drivers

The Indonesian deep decarbonization pathways combine strong action on the three pillars –energy efficiency and conservation, decarbonization of energy carriers, and fuel switching to low- and zero-carbon emitting energies (Figure 12 and Figure 13).

Figure 12. Illustrative decarbonization drivers

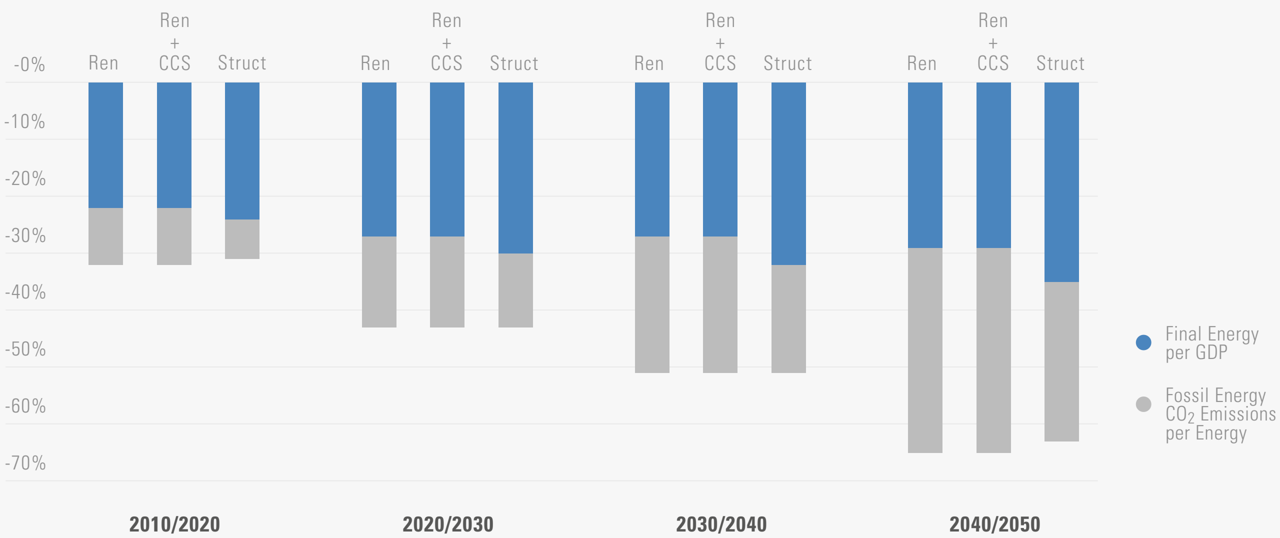
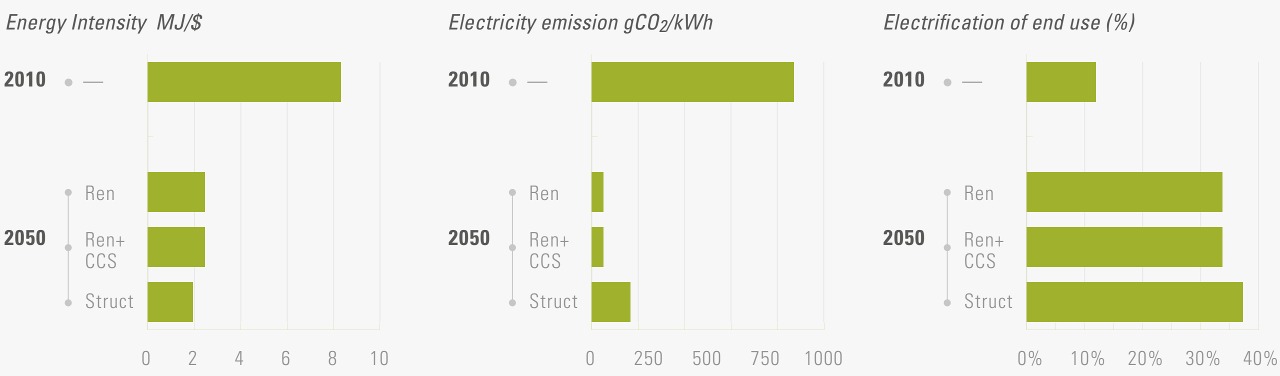


Figure 13. Pillars of decarbonization



In all three scenarios, energy efficiency improvements are deployed in all sectors, ensuring a strong decrease of the energy intensity of GDP. In the "Structural Change" scenario, structural changes in the economy (the decreased role of industry in GDP because of service sector substitution) lead to additional reduction in energy intensity of GDP, through a larger share of less energy-intensive industrial sectors.

Decarbonizing energy carriers means developing low-carbon sources to produce transformed energy. Notably in producing electricity, the diffusion of renewables, CCS, and nuclear energy ensures a steady decrease of the carbon intensity of power generation from 871 gCO_2/kWh in 2010 to 50 gCO_2/kWh in 2050, in the absence of structural change. In the "Structural Change" scenario, electricity remains significantly more carbon-intensive (reaching 166 gCO_2/kWh in 2050). This reflects the fact that when demand is lower, some margin of flexibility is created on the supply-side, on which carbon constraints are less stringent.

Finally, the deployment of lower-carbon-emitting energy sources is realized, in part, through fuel switching from coal to gas, oil to gas, and from onsite fuel combustion to electricity. This is measured in the sharp rise of the share of electricity in end-uses, from 12% in 2010 to 34%-37% in 2050. Additional fuel switching includes biofuels in transport, and biomass, biofuels, and biogas in industry.

When considering time profiles (Figure 12), we observe that energy efficiency is the main contributor to emission reductions in the short-term and increases only slightly over time, remaining at a fairly constant rate, from about 20% from 2010-2020 to about 30% from 2040-2050. When considering instead the emission intensity of energy (which results from the combination electrification of end use and decarbonization of electricity), a strong variation over time is observed: In the short term, the decarbonization of energy is very modest, but it becomes very important in the longer term. This reflects a general trend which is valid in most countries and can be explained by inertia when it comes to deploying low-carbon sources. They can be deployed at scale only after 2030, while energy efficiency measures can be deployed in earlier term (2010-2030).

Consistent with the above, the "Structural Change" scenario features more important energy efficiency, but more modest decarbonization of energy than the other scenarios.

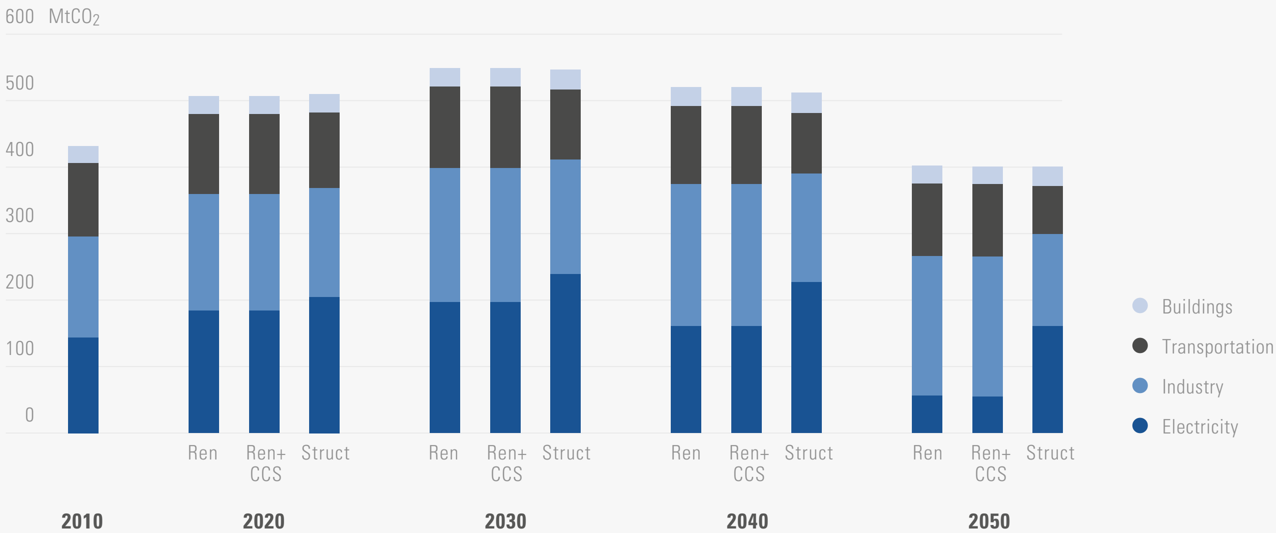
Emissions

The three decarbonization scenarios reach the same level of energy-related emissions in 2050 i.e. 402 million tons of CO_2 (Figure 14), corresponding to a decrease in terms of per capita emission, from 1.8 ton CO_2 in 2010 to 1.3 ton CO_2 in 2050. The emission profile over time is similar in all cases, with an increase over the 2010-2030 period in parallel with fast economic development, and then a decrease after 2030 when decarbonization measures are implemented at full scale.

In the absence of structural change in the economy (in the "Renewable" scenario and "Renewable+CCS"), emissions from industry increase over the period, representing more than half of national energy-related emissions in 2050. At the same time, the strong decarbonization of the power sector leads to a drastic reduction of emissions from this sector, despite rapidly growing production, in parallel with electrification. The transport and building sectors remain fairly constant, the technical improvements roughly compensating for the increase in activity levels in these sectors.

In the "Structural Change" scenario, the picture changes notably. Indeed, 2050 emissions from power generation are higher, but are compensated for by much lower emissions in industry thanks to structural change away from

Figure 14. CO_2 emission development scenarios



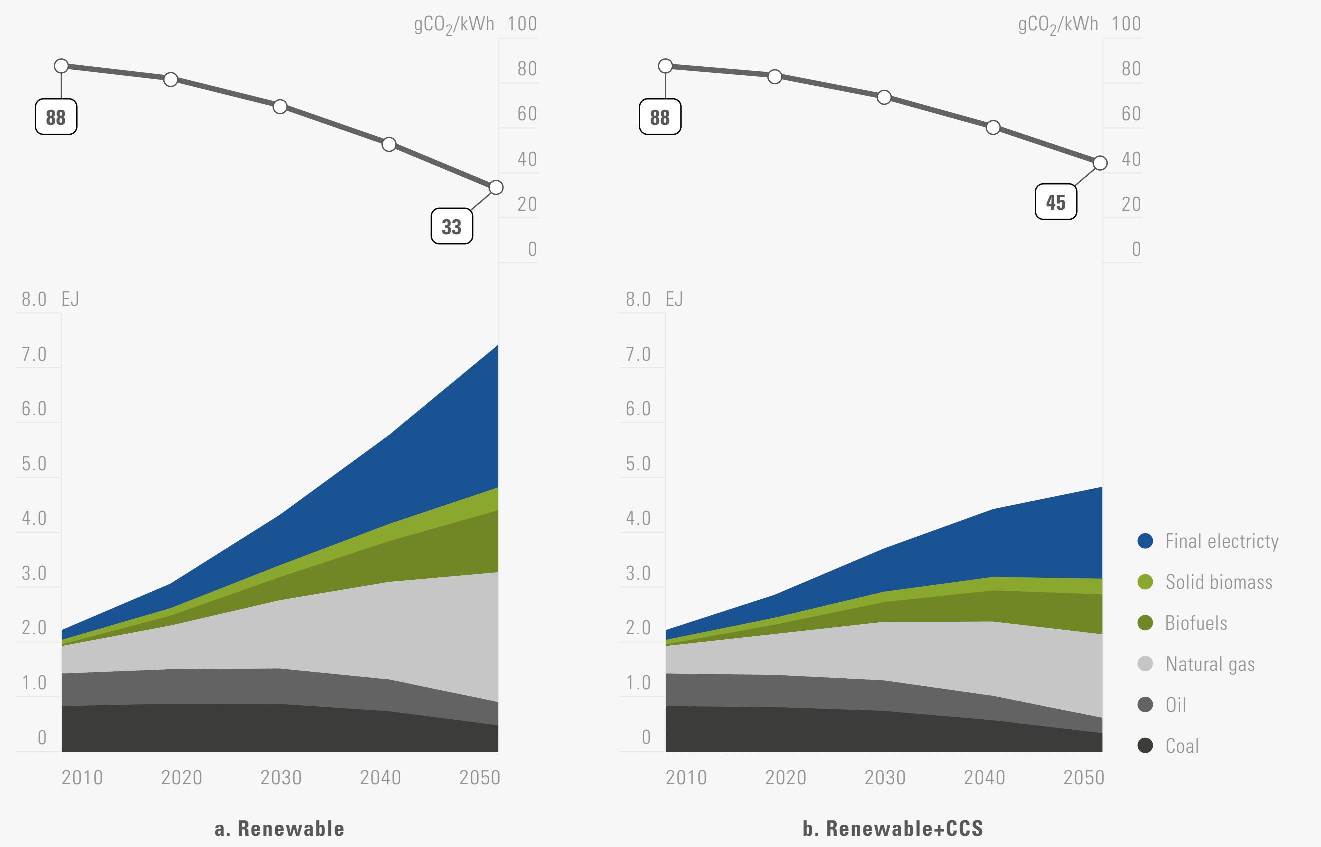
the fossil-intensive industrial sub-sectors. The transport sector also features lower emissions thanks to higher electrification of the fleet and efficiency diffusion.

5.2 Results: Final Energy Demand and Emission

Industry Sector

CO_2 emission reductions in industry are primarily realized thanks to energy efficiency improvement (decreasing energy intensity), which ensures a rather moderate increase in the amount of energy used, despite the sharp rise of industrial production in parallel with fast economic growth. In the absence of structural change (the "Renewable" and "Renewable+CCS" scenarios), the share of industry in GDP decrease from 27.8% to 18% between 2010 and 2050, which still means a multiplication by around 5.5 of industrial value added, given economic growth. But thanks to energy efficiency, final industrial energy is multiplied by less than 3.3. In the "Structural Change" scenario, this effect is similar: industry's share of GDP decreases to 12%, or a multiplication by 3.6 of industrial value-added by 2050, but industrial energy is multiplied only by 2.2. The deep decarbonization scenarios correspond to rather similar rates of decoupling between industrial energy and production, as captured by a 36%-39% reduction of energy content of industrial output between 2010 and 2050. Industrial fuel switching to lower-carbon fuels (notably gas) and bioenergy (solid biomass wastes and biofuels, which reach around 20% of final energy in 2050) as well as electrification (which represents around 35% of industrial energy in 2050) are crucial strategies for the decarbonization of the industrial sector. The result is a significant reduction of the emission intensity of fuels in industry from 88 gCO_2/MJ in 2010 to 45-33 gCO_2/MJ in 2050, according to the three scenarios. The most ambitious decarbonization of industrial fuels is reached in the scenarios with no structural change, where electricity is much more decarbonized.

Figure 15. Final energy demand and emission intensity in industry



Buildings Sector

The dynamics of the building sector, i.e. residential and commercial buildings, is driven first of all by population growth. It is also driven by economic development, which grows along with access to new energy services, as the wealth of the commercial sector grows, and it expands.

For the residential sector, increasing per capita income will increase energy consumption, but this will be partly compensated for by the diffusion of more energy-efficient appliances and the forecast of relatively moderate increases in the size of houses, saturating at about 20 sqm per capita because of space constraints in dense urban areas. Commercial buildings will increase their energy consumption, notably of electricity, as a consequence of the growth in the size of the service economy and the modernization of building equipment.

Decarbonization in the building sector would result primarily from fuel switching from oil to gas/LPG, and from fuels to electricity, along with the deployment of more energy-efficient electric appliances. Switching from on-site fuel combustion to electricity would reduce direct emissions from buildings, and with a decarbonized electricity generation sector, this switch would lead to emission reductions. The carbon intensity of building fuels decreases significantly, from 151 gCO_2/MJ in

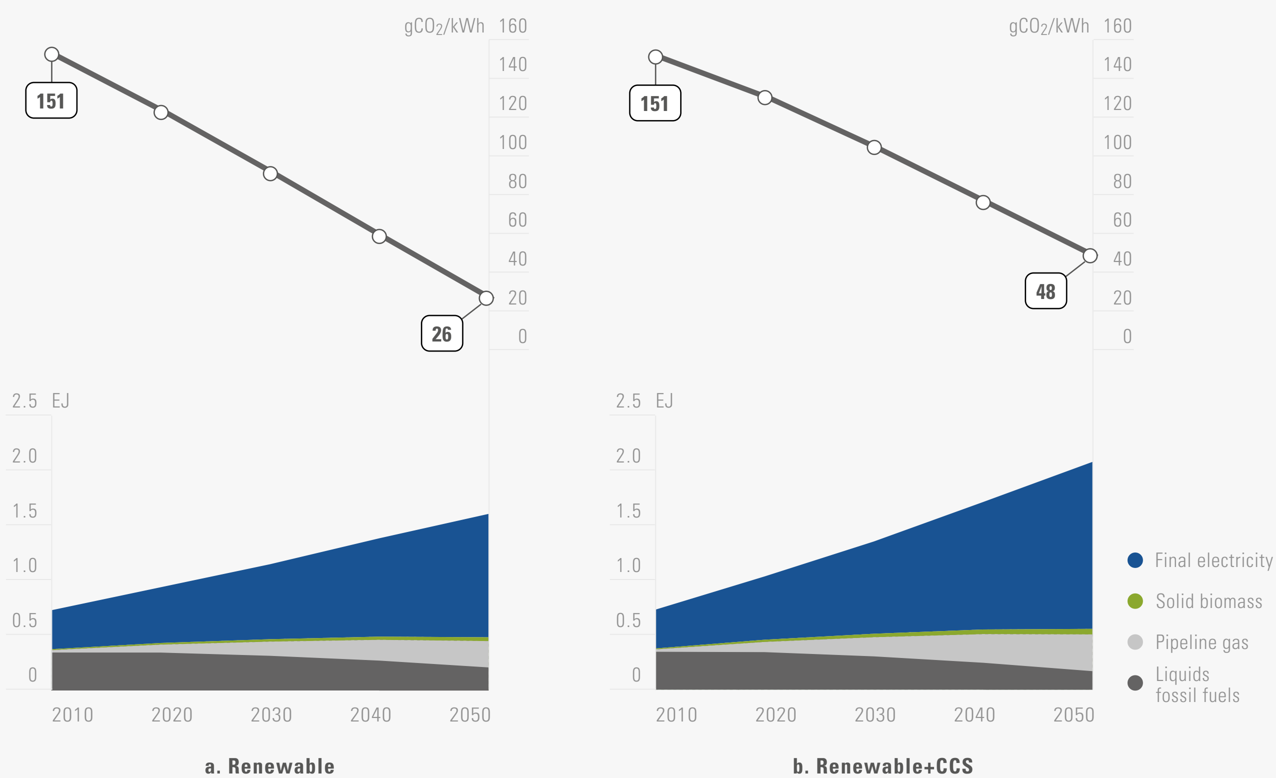
2050 to 26-48 gCO_2/MJ in 2050, depending on the magnitude of the decarbonization of electricity.

The energy consumption per capita in residential sector will increase by 30%-50%, according to the scenarios, notably with a multiplication by 2.0 to 2.3 of electricity consumption per capita as a consequence of enhanced access to electricity (electrification reaches almost 100%) and access to new energy services. In total, in absence of structural change, the energy consumption by the buildings sector will increase from 0.7 EJ in 2010 to 1.6 EJ in 2050 under the "Renewable" or "Renewable+CCS" scenarios, reaching 2.1 EJ under the "Structural Change" scenario due to the higher growth of the service sector (as a substitute for the industrial sector).

Transport Sector

Energy consumption in the transport sector is expected to increase significantly with economic development and population growth. In passenger transport, individual mobility rises from 4700 to more than 7000 p-km per capita between 2010 and 2050 in all three decarbonization scenarios, leading to approximately a doubling of total mobility. Car travel increases by 70%-78%, whereas travels by public transport increase even faster (multiplied by 2.3 to 2.7). This means that mass public transport increases its modal share under deep decarbonization, rising from 40% of terrestrial transport in 2010 to 46%-52% in 2050. A more important role is played by public transport in the structural change scenario. Freight transport energy demand experiences

Figure 16. Final energy demand and emission intensity in building



a multiplication by 2.7-2.9 between 2010 and 2050. Under the “Structural Change” scenario, the growing share of the service sector makes transport demand higher than that of the “Renewable” or “Renewable+CCS” scenarios. However there is a significant decoupling of transport energy demand from economic growth in all three scenarios. Even if rail and water freight develops rapidly, road transport remains the dominant mode for freight transport, representing a 60%-75% modal share.

The modal shift to mass transport, and the deployment of energy-efficient vehicles, moderates the increase in energy needs even as mobility increases. And the electrification of vehicles (20% - 40% share of transport load), fuel switching to less-carbon emitting fuels (oil to gas in freight most notably), and extensive use of biofuels drive a decrease in the carbon content of transport fuels, from 73 gCO_2/MJ to 49-39 gCO_2/MJ.

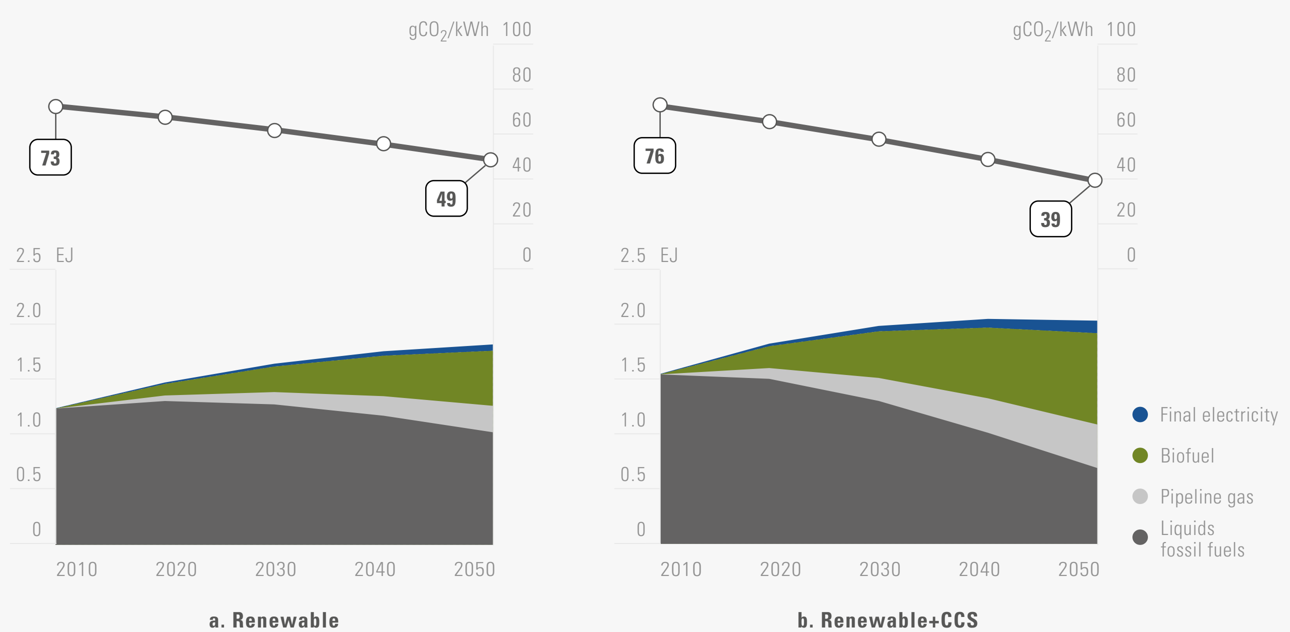
5.3 Results: Energy Production and Emissions

Electricity Generation

The decarbonization of electricity is a crucial dimension of the scenarios. Only by decarbonizing electricity can end-use equipment be electrified, the population achieve increased access to electricity (an almost 100% electrification rate by 2050) and Indonesian achieve a decarbonization process.

As the result of a significant increase in electrification of end-use, electricity generation increases dramatically from 165 TWh in 2010 to about 900-1000 TWh in 2050. The "Renewable" and “Renewable+CCS” scenarios have the same level of electricity generation, given their identical energy demand, and feature very strong decarbonization as measured by the drop of the carbon intensity of electricity from 871 gCO_2/kWh in 2010 to 51 gCO_2/kWh in 2050. But there are

Figure 17. Final energy demand and emission intensity in transport



clear differences in the options which are mobilized to operationalize this decarbonization.

Under the "Renewable" scenario, decarbonization is achieved by large-scale deployment of all sources of renewables, notably solar, hydro, and geothermal, which contribute 20%, 20% and 18% of electricity production respectively. Large-scale utilization of hydropower can only be achieved if sub-sea long-distance cable technology is already advanced and commercially available, because the location of a large hydro (25 GW) resource is in East Indonesia on the island of Papua, while the demand center is located 3000 km away in Western Indonesia (Jawa and Sumatera). Decarbonization of electricity through renewables will require large-scale deployment of geothermal, up to 25 GW (in 2050), about 85% of the size of the total known Indonesian resource. Geothermal resources are scattered in the mountains along the western and central islands of Indonesia. Its deployment also faces the challenge of a mismatch between demand centers and the location of the resources. However, this challenge is not as difficult as that of hydro development. The location of geothermal resources in the western and central islands is in the same region as the demand centers. Another challenge in geothermal deployment is related to the quality of the resource. About 40% of the resources have low-quality steam, which may be not economically attractive to develop using current technology. Therefore, large scale geothermal development (including developing the low-quality resource) is subject to the availability of more advanced and economical technology for its exploitation.

Coal remains an important source during the evolution of Indonesian decarbonization; it even expands in absolute terms until 2030 (although it decreases as a share of total electricity supply). This is necessary given the time needed to develop the other energy sources at scale; coal then phases out almost completely after 2030. Nuclear power is also developed, but with a significant contribution only at the long-term horizon where it represents 16% in 2050.

Under the "Renewable+CCS" scenario, the deployment of large quantities of coal and gas with CCS (which represent 37% of the mix in 2050) leads to a lower deployment of renewable sources, with a particularly strong effect on hydro and geothermal sources, which together represent only 24% of the mix in 2050. Solar is less affected, representing 15% in 2050. The lower share of hydro and geothermal needed to achieve deep decarbonization in this scenario proves the robustness of Indonesian deep decarbonization; in case sub-sea cable and advanced geothermal technology are not yet available, decarbonization may still be achieved through (a reduced share of) renewables, complemented by fossil-fuel power equipped with CCS.

Interestingly, the deployment of CCS also induces a reduction of the role of nuclear, which is reduced by 40% compared to the "Renewable" scenario. In the short-term, the difference between the two scenarios is less marked, given the small contributions of CCS by 2030.

In the "Structural Change" scenario, electricity demand is much lower than in the two other scenarios thanks to a lower level of industrial activity and deeper implementation of energy efficiency measures. The most notable effect is the relatively high share of residual fossil fuels without CCS (notably gas), even in 2050. This illustrates that when demand is lower, the pressure on the supply-side decarbonization is less important, as measured by the more moderate reduction of the carbon intensity, which reaches levels more than three times higher than in the other cases (166 gCO_2/kWh). In this "Economic Structural Change" scenario, geothermal is the only low-carbon option which is developed at a scale comparable to the other scenarios. Hydropower, solar, and nuclear are more moderately diffused.

Figure 18. Electricity generation and carbon intensity of electricity

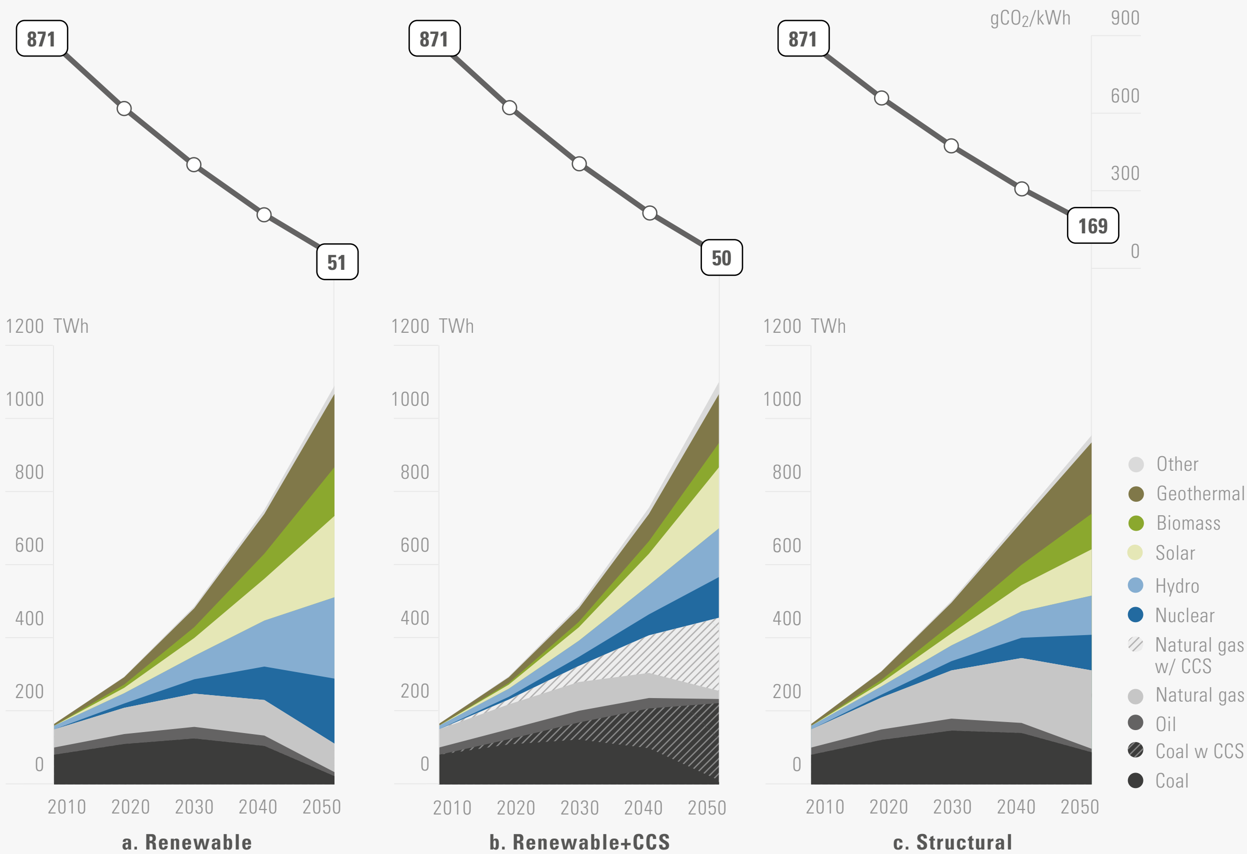
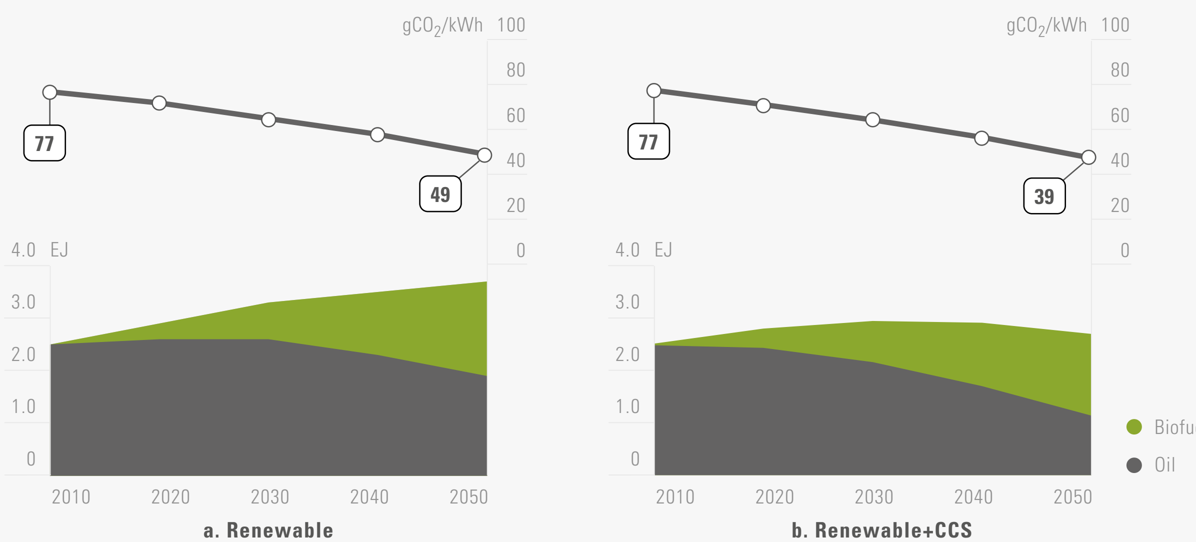


Figure 19. Liquid fuel production and emission intensity of fuel



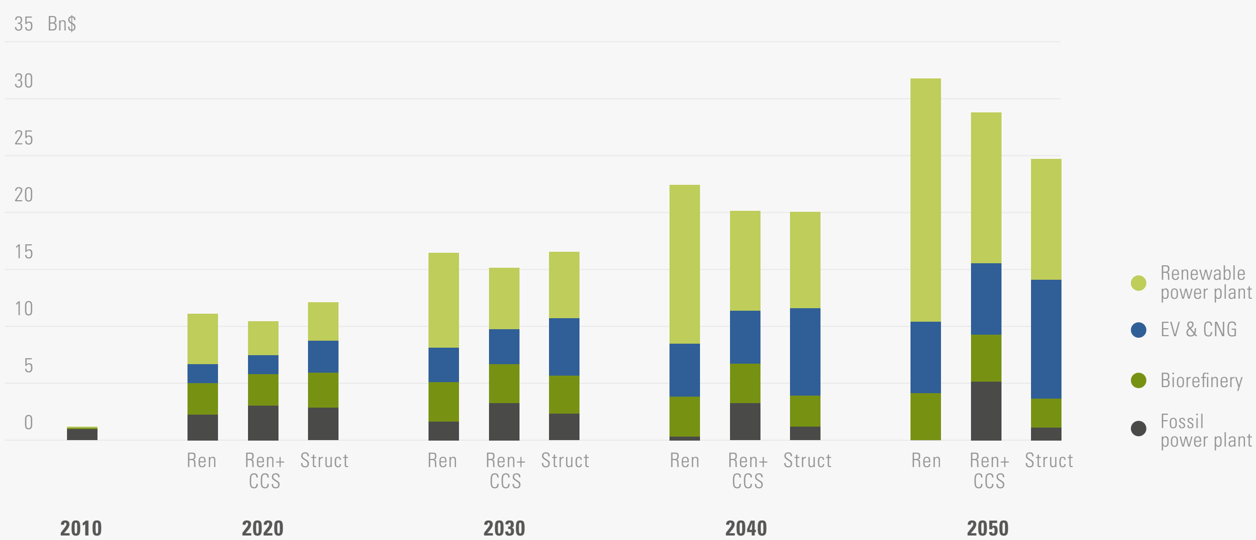
Liquid Production

Liquids are a crucial from of energy, notably in the transport sector, and to a lesser extent in industry (see discussion in the previous section). In order to ensure decarbonization of this energy, in all three scenarios biofuels are deployed at an important scale as a substitute for oil. The absolute production of biofuels is lower in the "Structural Change" scenario because there is less energy demand, associated with a lower level of industrial activity in the economy (it is substituted by service-sector businesses). But "Structural Change" requires a higher share of total liquids (up to 57% in 2050); the two other scenarios feature biofuels production that is 12% higher, but a lower level of liquid production: 47% (Figure 19).

8. Investments

Decarbonization requires investing specifically in low-carbon options, notably low- or zero-carbon emitting power plants, low- or zero-carbon fuel production units, and the procurement of low- or zero-carbon emitting vehicles. Investment is needed for Indonesia's decarbonization in these three key sectors. Indeed, the three scenarios all feature significant, steady increases in investments (Figure 20).[16] These decarbonization investment needs are calculated using the DDPP Investment calculator developed by the SDSN/IDDRI project team. The investment calculator considers the learning curve of each technology. Among the three scenarios, the "Structural Change" scenario has slightly lower investment needs in the long term, notably in energy supply (power generation and biorefineries) thanks to the more moderate capacity additions required in this scenario under more moderate energy production. On the other hand, higher investments in low-carbon, demand-side technologies (electric and compressed natural gas vehicles) are needed consistently, giv-

Figure 20. Investment needed for capacity addition of power plant and refineries and for vehicle procurement



16 Several caveats must be noted for these assessments. First, the investment needs presented in this section do not include the additional infrastructure needed to support the operation of plants such as construction for gas pipelines, regasification plant (imported LNG), and to support the operation of electric vehicles or CNG such as recharging/refueling stations. Second, the costs associated with energy efficiency measures in buildings and industry have not been included.

en the focus on a demand-side, low-carbon evolution in this scenario.

To put these numbers in perspective, we assess them as a share of GDP. Given the GDP trends discussed in Table 4, investments in low-carbon options for these three key activities correspond to a maximum of 1.22% of GDP in 2020, before decreasing gradually towards 0.54% in 2050. This means that these investments, although not negligible, are perfectly manageable for the Indonesian economy. This is even truer if we compare these investment needs with the total macroeconomic investment in Indonesia, which has been rising from 22% of GDP in the early-2000s to about 35% of GDP in early-2010s (World Bank data). Even if one assumes that gross capital formation reverts to the lower end of the range, investment in low-carbon options would still represent less than 5% of total investments in the Indonesian economy. Additionally, it must be noted that investments in low-carbon technologies under deep decarbonization happen in parallel with a significant reduction of fossil production (for both domestic uses and exports), triggering, in turn, a reduction of investments in the fossil-fuel sectors.

6 Challenges, Opportunities, and Enabling Conditions

Indonesia's decarbonization pathway relies primarily on technological change, indeed on a wide range of low-carbon technologies: electric vehicles, high-efficiency power plants, CCS, and others. Some of these are still in the demonstration phase, or require important technical progress if their cost is to decline, which is a condition for their wide deployment. Thus realizing the deep decarbonization pathway is dependent on the development, and maturing in the coming years, of these crucial technologies.

There are also some proven decarbonizing technologies (including solar power, biofuel, and geothermal) which are still more expensive than competitor technologies and fuels (petroleum diesel, coal power plants). Deployment of these renewable requires further technical development so they become available at competitive, affordable prices. This also requires the right energy-pricing policy.

Most of the technologies envisaged to be used in the pathway are imported. It is imperative, therefore, that Indonesia to begin developing these technologies domestically. To speed up the process, efficient and large-scale international cooperation is a crucial enabling condition.

In addition, the deep decarbonization transformation is characterized by a need for massive infrastructure development, e.g. infrastructure to enable mass public transport, new railways, gas transmission, subsea electrical transmissions, and CCS facilities. Therefore, one of the main challenges of the pathway is how to finance the infrastructure investment, and most notably, how to re-direct investment flows towards these low-carbon options.

We have seen that the deep decarbonization transformation requires a scale-up in low-carbon technologies and infrastructure, but that this rise can be absorbed by the Indonesian economy, given its fast growth, which can be expected to continue to offer important investment opportunities in the future. The main challenge, then, lies in the country's capacity to re-orient investment decisions towards low-carbon solutions, in a drastic change compared to past and current decisions that are largely targeted on developing of fossil energies.

Deployment of nuclear power plays a small role. But it is also potentially important, to ensure the decarbonization of electricity at the scale that will be required for the deep decarbonization of the energy system. Nuclear poses a special challenge of social acceptability, which would require a social campaign and public debates.

The Government of Indonesia in 2009 announced a non-binding commitment to reduce 26% of its emission in 2020 (compared to a business-as-usual development path). However, being a non-Annex I country, climate concern has not yet been fully internalized into the Indonesian development agenda. To embrace the deep decarbonization pathway, the government has to first internalize climate change, making it an integral part of the national development agenda.

In summary, enormous efforts will be needed to realize the pathway: internalizing climate change into the national agenda, attracting financing for infrastructure investment and technology development, technology transfer, a social campaign to facilitate the social acceptance of nuclear energy, and the right energy-pricing policy for renewable sources. To overcome some of these challenges, international cooperation is needed, especially when it comes to infrastructure financing and technology transfer. The government must begin to seek international cooperation, and find assistance for infrastructure development. In addition, the government must seek international partners for the transfer of the technologies necessary for deep decarbonization.

This study envisages that deep decarbonization poses enormous and unprecedented challenges. However, this study also envisages that deep decarbonization in Indonesia in fact holds out economic opportunities, and therefore goes hand-in-hand with the country's national development objectives. Developing renewable energy sources, and other less-carbon emitting technologies, could stimulate economic development and create jobs. Energy-efficiency measures could improve economic productivity. A deep decarbonization scenario for Indonesia also assumes that the country's economic structure would shift towards a more service-oriented economy and that, in a decarbonized world, Indonesia's economy would be less dependent upon unstable revenues from fossil fuel exports. Deep decarbonization also holds additional benefits, most notably two: reduced local pollution from transport, industry, power plants, and residential energy. And the improved energy security that would be gained by developing the potential of domestic renewables.

The Indonesian deep decarbonization scenarios were built upon assumptions that the country maintains steady economic growth, has built sufficient infrastructure to enable electricity access for almost all households, and reduces the poverty rate. The implication is that Indonesia deep decarbonization is compatible with the country's socioeconomic development objective and priorities.

7 Conclusions

1. This study finds that Indonesia has the technical potential to deeply reduce its energy related CO_2 emission, to a level that will significantly contribute to the global efforts to prevent 2°C temperature increases in 2050. The three decarbonization scenarios envisaged in this study ("Renewable," "Renewable+CCS," and "Economic Structural Change") will all achieve about the same CO_2 emission level of 402 million tons in 2050, which in per capita terms translates to 1.3 ton CO_2/capita.

2. "Renewable," "Renewable+CCS," and "Economic Structural Change" scenarios all show that decarbonization could be technically achieved through the implementation of three decarbonization pillars: energy efficiency measures, electrification of end-use, and decarbonization of the electricity sector.

3. In line with, and to support the projected economic growth of between 5.4% - 5.8% per year, emissions will continue to increase in the 2010-2030 period (due to economic development), and then decrease afterwards (as a result of decarbonization measures). It is crucial to note, however, that the decrease of emissions in the long-term does not mean delaying action, but rather suggests following a streamlined, gradual development of low-carbon options in the short-term. This is crucial both to make available adequate infrastructure in due time, but also to avoid carbon lock-in if carbon-intensive infrastructure and technologies are installed over the next decade
4. The "Renewable" scenario assumes the total deployment of renewable energy (solar, hydro, geothermal) to replace most, if not all, fossil-fueled power plants. In addition to renewables, some fraction of the power plants would be nuclear-powered. This scenario assumes that large size solar PV are deployable, and that large hydro resources in Papua (eastern Indonesia) is utilizable, to cater demand in the western part of Indonesia through long distance sub-sea cables. In case long distance sub-sea cable technology is not yet deployable, decarbonization to 1.3 ton CO_2/capita is still achievable by combining renewables and fossil power plants equipped with CCS. The "Renewable+CCS" scenario is a back-up scenario for the "Renewable" scenario. I.e., if a sub-sea cable cannot be deployed, there is an alternative scheme to achieve the same decarbonization target.

5. Another alternative decarbonization pathway is transforming the country's economy towards a less energy-intensive one, i.e. through structural change towards more service- oriented industries. The "Economic Structural Change" scenario will result in lower energy demand, and combined with the three decarbonization pillars and deployment of renewables, make the decarbonization target more achievable than the first two scenarios.

6. Deep decarbonization requires an enormous amount of investment to build infrastructure and deploy lower-carbon-emitting technologies which are, in general, more expensive than conventional technologies. For Indonesia, where climate-change mitigation does not yet greatly concern the government or society in general, this large investment required for decarbonization is a major challenge. However, these investment needs still represent only a small fraction of total investments throughout the economy, especially in the context of the country's fast economic growth, which is assumed in our scenarios. The main challenge, therefore, is to develop adequate schemes and policy incentives to re-orient investments towards low-carbon options. This must include investing in infrastructure for deployment at scale, and in due time.

Annex

The Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP) is an international initiative, aimed at understanding and demonstrating how major emitting countries can transition to low-carbon economies, and in doing so move towards the internationally agreed 2°C target. Led by the Institute for Sustainable Development and International Relations (IDDRI), Paris and the UN Sustainable Development Solutions Network (SDSN), it comprises 16 countries that account for over 70% of current global greenhouse gas emissions. Participating countries include Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

This is a unique collaborative assessment. For the first time, a comprehensive analysis is being undertaken from the national perspective, to explore radical emission reduction pathways. The key benefit is that the analyses under the DDPP take account of national circumstances. In turn, it is hoped that this establishes greater traction with national stakeholders, and shows how the type of pathways required to move us towards the 2 °C target can be operationalised at the country level. An important feature of DDPP is that it aims to ask how far all countries can decarbonise. Therefore, there is no explicit discussion of differentiating targets and resolving the equity dimension. The principle is that all countries need to act, and decarbonise strongly. However, it is recognised that further consideration of enabling mechanisms is required, including how developed countries can support action in developing countries through financing and technology transfer.

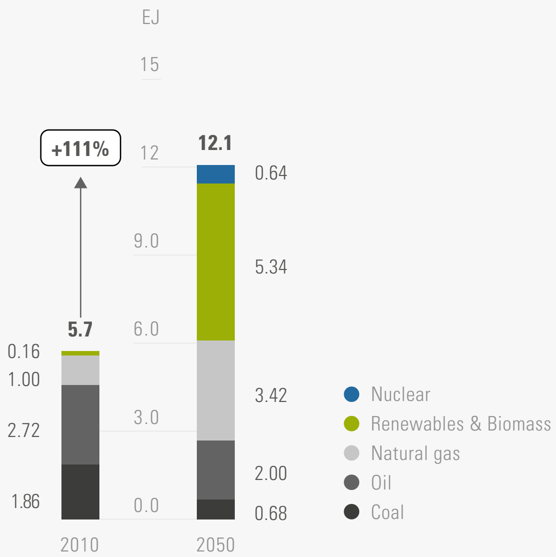
An interim DDPP analysis was published in September 2014 (SDSN & IDDRI, 2014), and presented to Ban Ki Moon at the World Leaders' Climate Summit. It presents a global pathway that shows a CO_2-energy emissions level of 12.3 Gt by 2050, down from 22.3 Gt in 2010, representing a 45% decrease over the period, and a 56% and 88% reduction in emissions per capita and the carbon intensity of GDP, respectively. While not sufficient to make staying below the 2 °C limit likely, this initial pathway provides the basis for further iterative analysis in 2015 to explore deeper decarbonisation pathways. The interim report also highlighted a number of important findings, including the need for global cooperation on technology research and development, challenges to abatement action in specific sectors, and the need for Deep Decarbonisation Pathways (DDPs). The report concludes that DDPs are crucial 'to developing a long-term vision for deep decarbonization and shaping the expectations of countries, businesses, and investors about future development opportunities. The DDPP and similar processes afford a unique opportunity for teams to work together across countries to map out how the global 2 °C limit can be operationalized and achieved at the country level.'

Standardized DDPP graphics for Indonesia scenarios

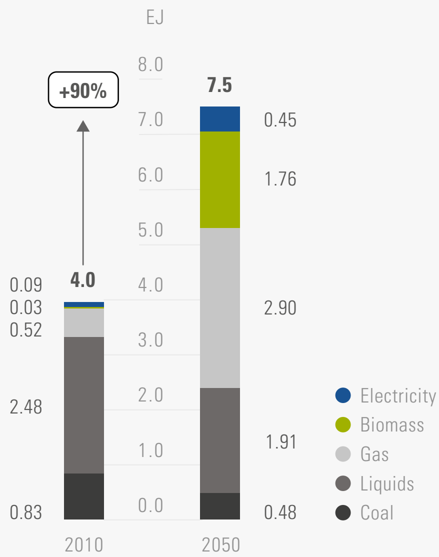
ID - Renewable
ID - Renewable + CCS
ID - Economic Structural Change

ID - Renewable

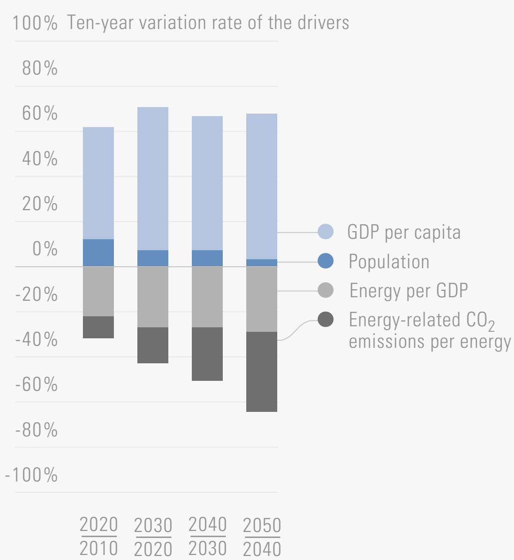
Energy Pathways, Primary Energy by source



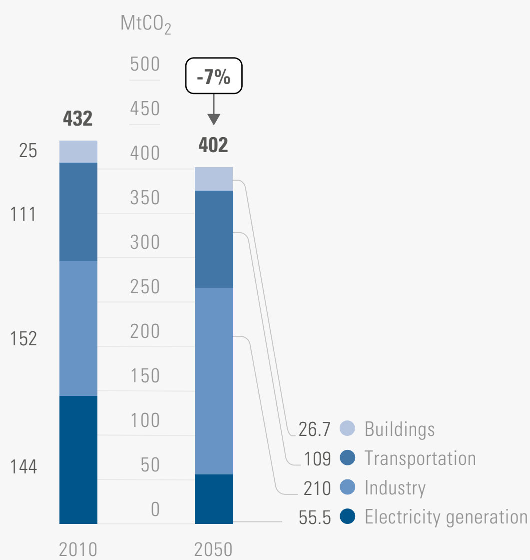
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

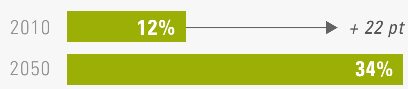
Energy efficiency

Energy Intensity of GDP, MJ/$

Decarbonization of electricity

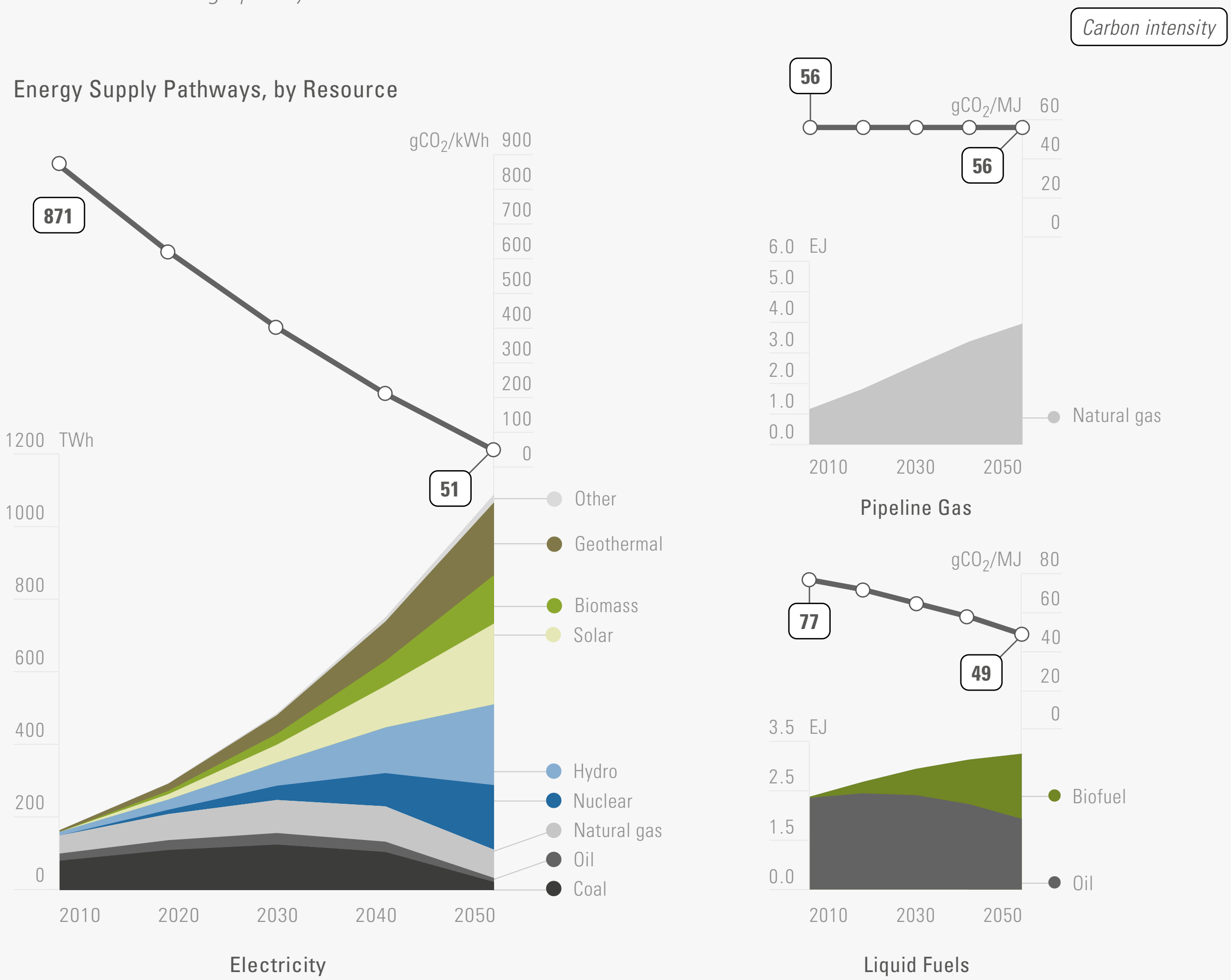
Electricity Emissions Intensity, gCO_2/kWh

Electrification of end-uses

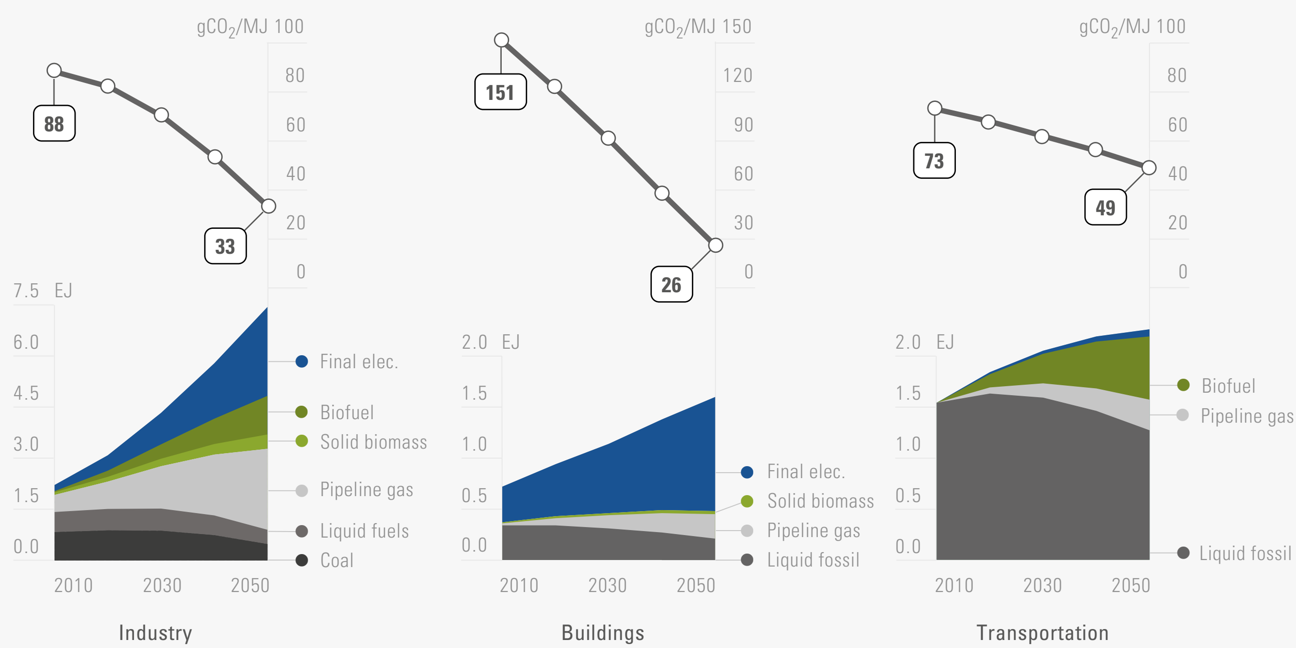


Share of electricity in total final energy, %

Energy Supply Pathways, by Resource

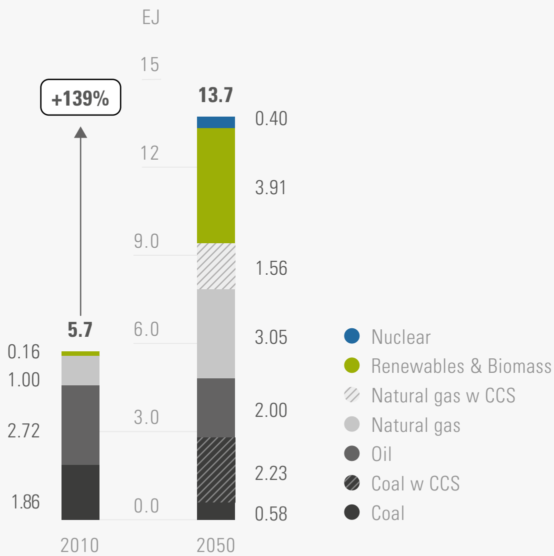


Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050

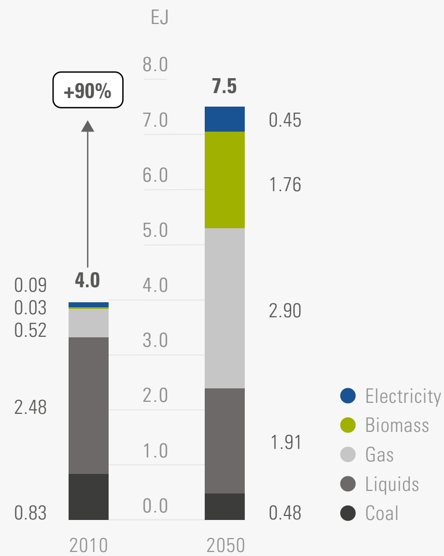


ID - Renewable + CCS

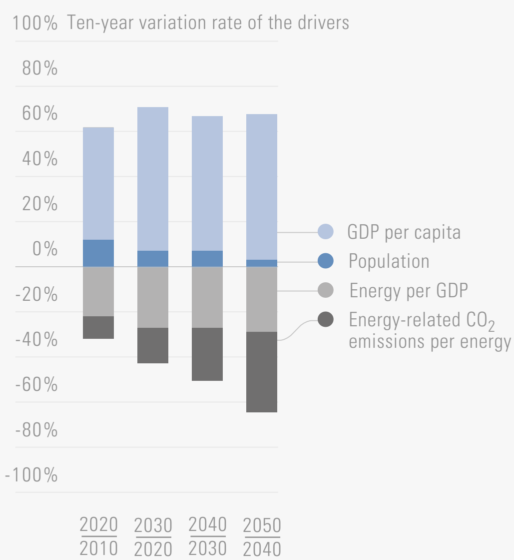
Energy Pathways, Primary Energy by source



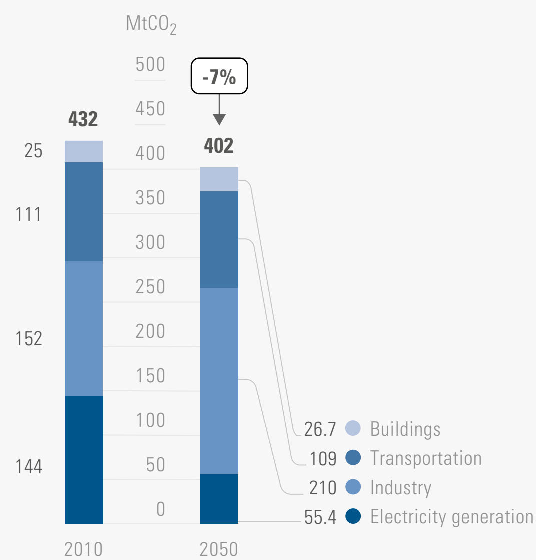
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector

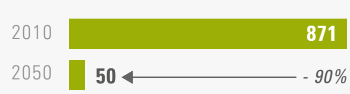


The Pillars of Decarbonization

Energy efficiency

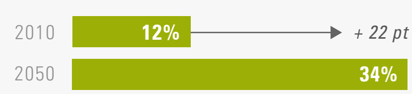
Energy Intensity of GDP, MJ/$

Decarbonization of electricity



Electricity Emissions Intensity, gCO_2/kWh

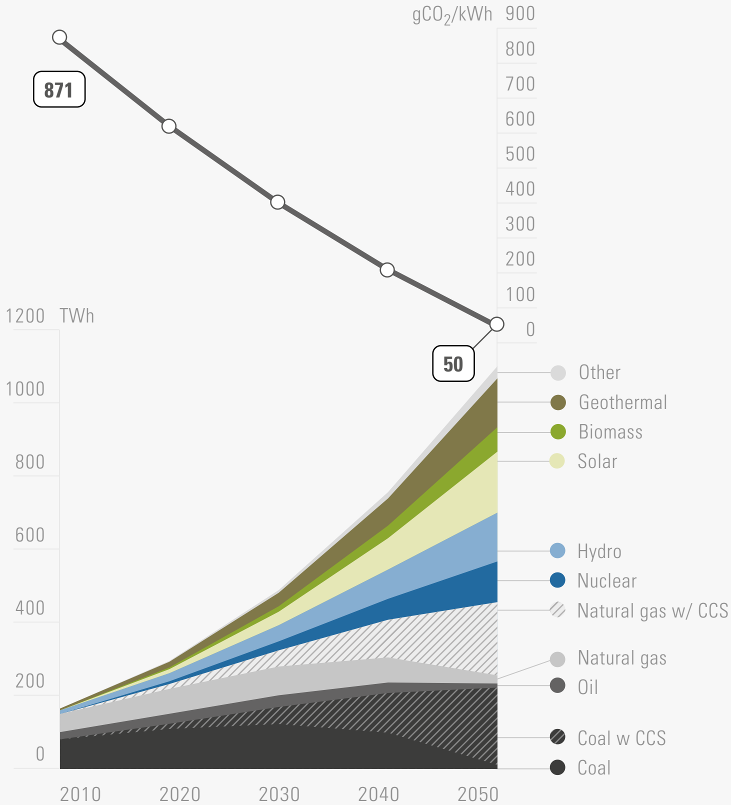
Electrification of end-uses



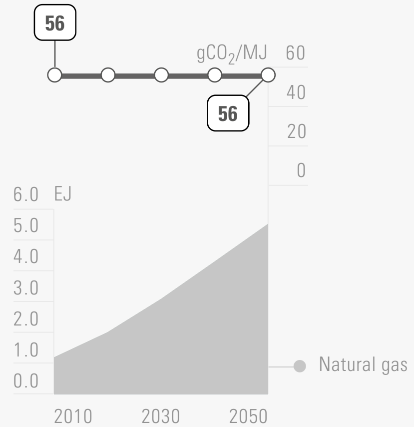
Share of electricity in total final energy, %

Carbon intensity

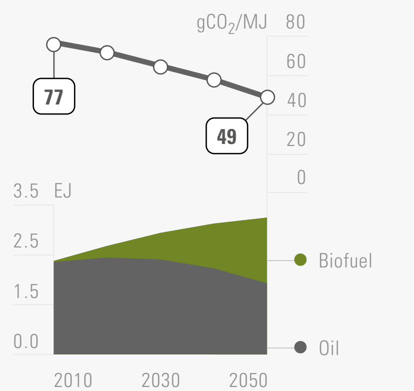
Energy Supply Pathways, by Resource



Electricity

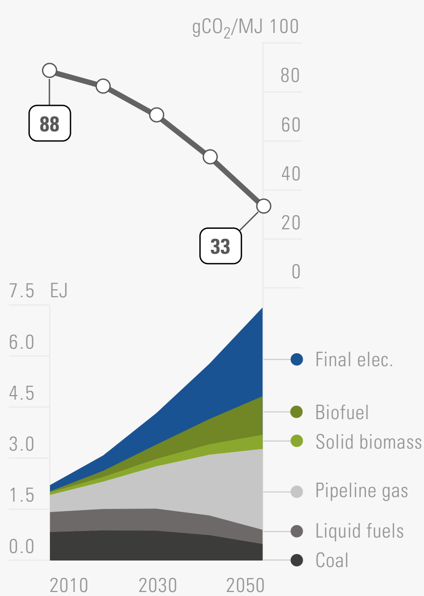


Pipeline Gas

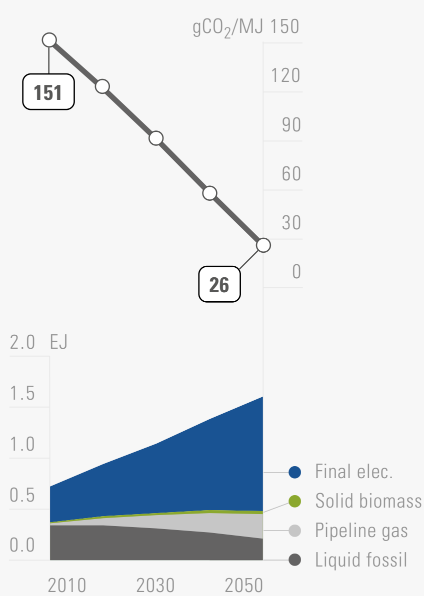


Liquid Fuels

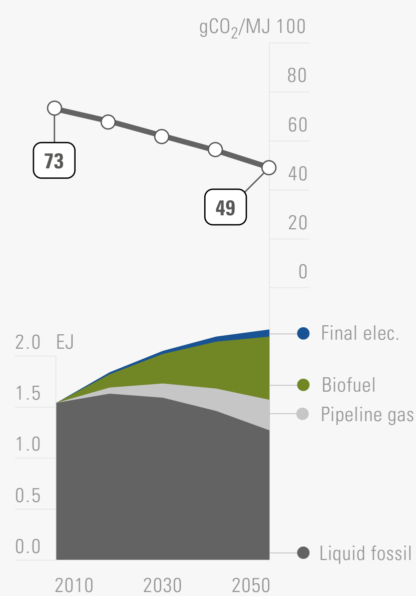
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



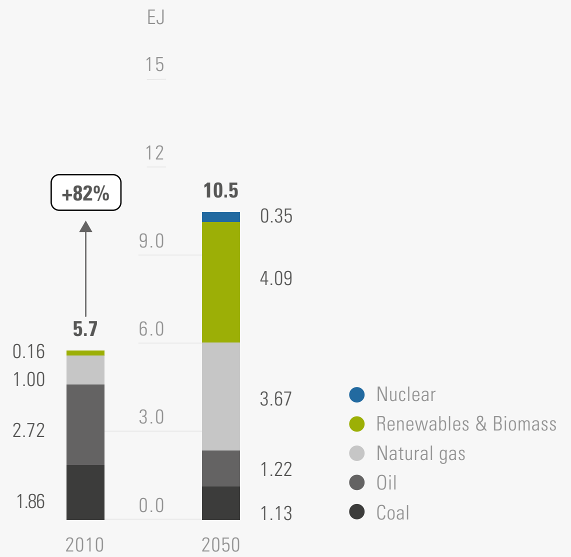
Buildings



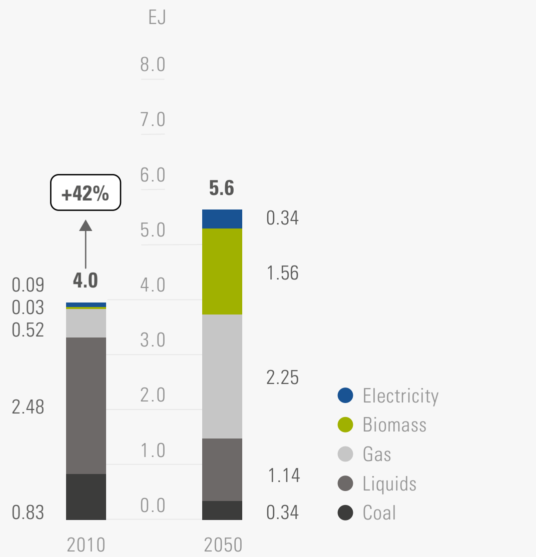
Transportation

ID - Economic Structural Change

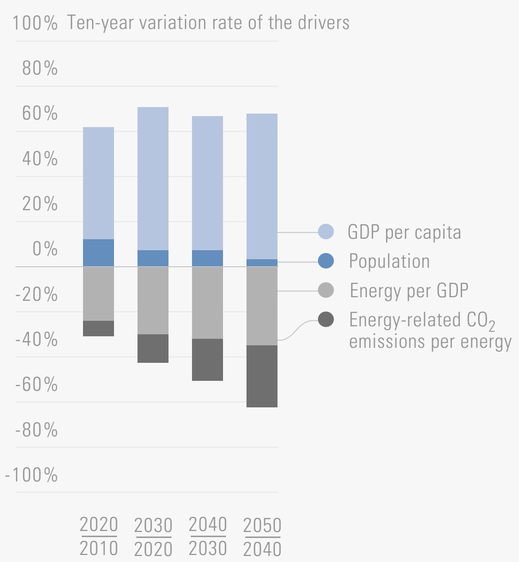
Energy Pathways, Primary Energy by source



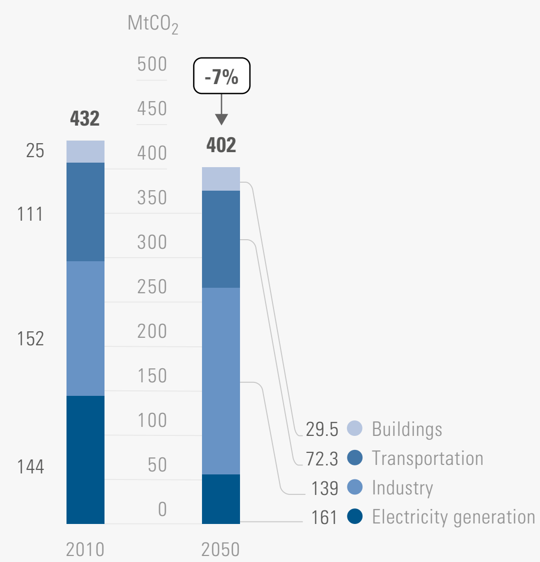
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

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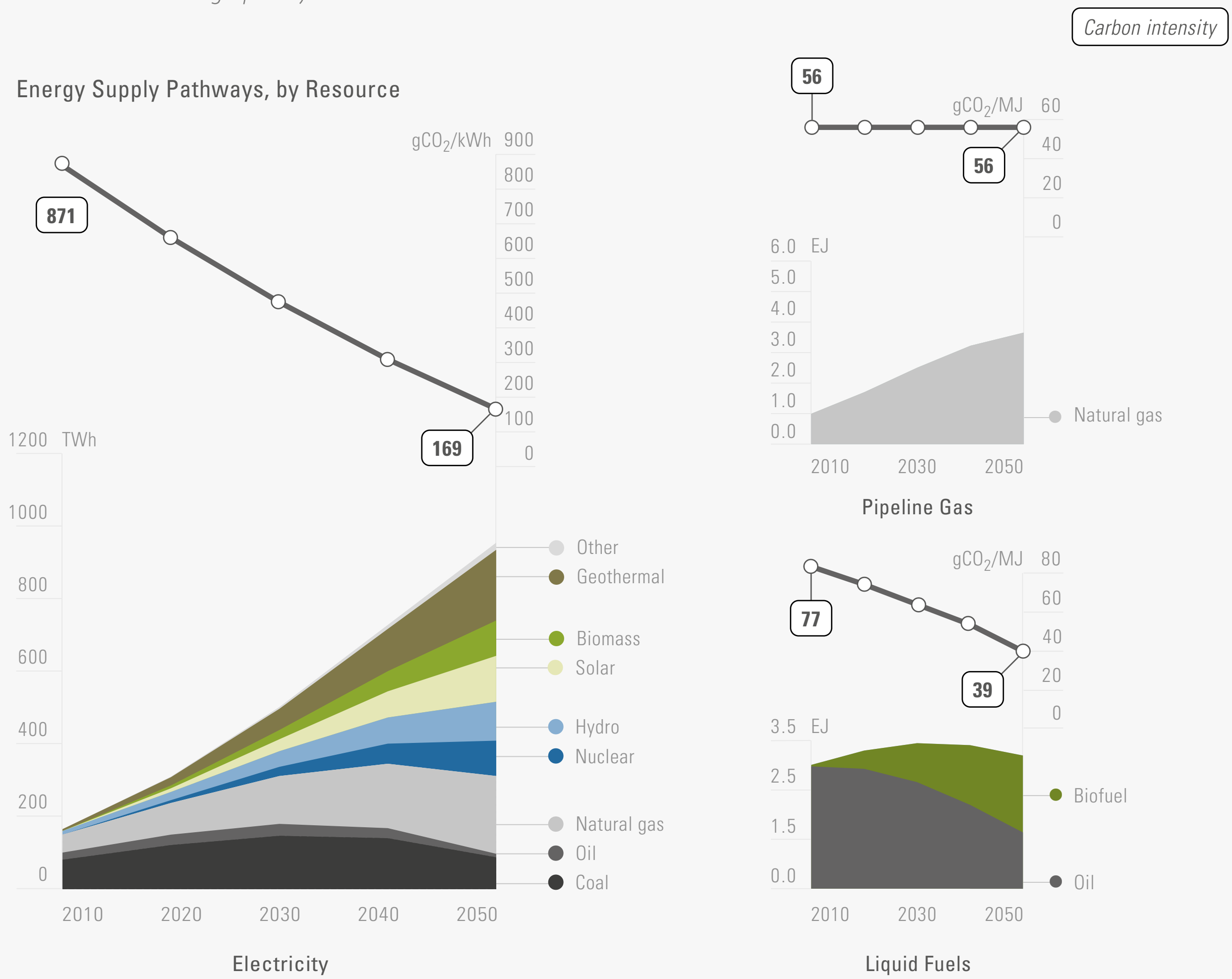

Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050