IRENA
International Renewable Energy Agency

REmap
A Renewable Energy Roadmap

RENEWABLE ENERGY PROSPECTS:

INDONESIA

March 2017

ISBN 978-92-95111-18-9 (Print)

ISBN 978-92-95111-19-6 (PDF)

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

Acknowledgements

This report has benefited from the valuable comments and guidance of the Indonesian Ministry of Energy and Mineral Resources (MEMR), with special thanks to Maritje Hutapea and Ezrom Tapparan.

Additional contributions during the analysis and review were provided by Gareth Davies (Aquatera), Abdul Kholik (Azetsurya), Togar Sitanggang (Indonesian Palm Oil Association - GAPKI), Tjut Devi (German Agency for International Cooperation - GIZ), Bawa Santosa (Indonesian Renewable Energy Society - METI), Budi Mulyono (Perusahaan Listrik Negara - PLN) and Carina van der Laan (University of Utrecht). The report benefited significantly from input provided by external expert review by Pradeep Tharakan (Asian Development Bank), Markus Steigenberger and Daniel Argyropoulos (Agora Energiewende), Jacob Høgh and Nadeem Niwaz (Danish Energy Agency), Bill Meade and Ami Indriyanto (USAID-ICED), and Tim Williamson (US Department of Energy State). The report also benefited greatly from input and comments provided during two expert review workshops held in Jakarta, in April and July 2016. IRENA would like to thank all those that attended for their valuable input. IRENA colleagues Rabia Ferroukhi, Diala Hawila, Yasuko Inoue, Divyam Nagpal and Nicholas Wagner also provided valuable comments. Finally, a special thanks is due to Andre Susanto, who worked on the report as a consultant and provided invaluable input and support throughout the project.

IRENA is grateful for the generous support of the Federal Ministry for Economic Affairs and Energy of Germany, which made the publication of this report a reality.

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Citation

IRENA (2017), R*enewable Energy Prospects: Indonesia, a REmap analysis,* International Renewable Energy Agency (IRENA), Abu Dhabi, **www.irena.org/remap.**

FOREWORD

Indonesia is the largest country in the Association of Southeast Asian Nations (ASEAN) in terms of energy consumption. Across the country's more than 17,000 islands, energy demand is growing rapidly.

Although reliance on domestic coal, as well as imported petroleum products, has increased in recent years, Indonesia has started adding more renewable capacity to its energy mix. The country aims to achieve 23% renewable energy use by 2025, and 31% by 2050, as part of its plans to reduce greenhouse gas emissions in line with the objectives of the Paris climate agreement.

Along with some of the world's greatest geothermal and hydropower potential, Indonesia also possesses abundant resources for solar, wind, ocean and bioenergy development. In addition to power generation, these sources could support heating, cooling and transport applications.

To help countries like Indonesia harness this potential, REmap – the global roadmap from the International Renewable Energy Agency (IRENA) – presents a range of technology and resource options, as well as key insights on the opportunities and challenges ahead.

As this REmap country study shows, Indonesia's renewable energy target for 2050 could be achieved as soon as 2030, given the right policies and investments starting today. Beyond power generation, energy end-uses require closer attention for the full potential of renewables to be achieved. At the same time, a sustainable supply chain needs to be in place to support the expanding use of modern bioenergy.

The benefits of such accelerated uptake for Indonesia would greatly outweigh the costs. In economic terms, the net reduction of energy system costs, combined with the avoidance of air pollution and carbon-dioxide emissions, would save up to USD 53 billion per year, or an estimated 1.7% of Indonesia's 2030 GDP.

But harnessing this potential requires over USD 16 billion of investments per year for the years between 2015 and 2030, from modest levels at present. Recent market developments suggest that Indonesia is on the right path, with renewable energy investments already on the rise.

If Indonesia continues to follow this course, it can play a leading role, not only regionally but also internationally, in the advancement of the global energy transition. IRENA stands ready to work closely with Indonesia as the country strives for a sustainable energy future.

Adnan Z. Amin

Director-General

International Renewable Energy Agency

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°C	degrees Celsius
ACE	ASEAN Centre for Energy
ASEAN	Association of Southeast Asian Nations
BATAN	National Nuclear Energy Agency of Indonesia
BMKG	Indonesian Meteorological Agency
BPPT	Indonesian Agency for the Assessment and Application of Technology
B10	10% biodiesel blended with petroleum diesel
B15	15% biodiesel blended with petroleum diesel
B20	20% biodiesel blended with petroleum diesel
B30	30% biodiesel blended with petroleum diesel
CHP	combined heat and power
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
COP21	Twenty-first session of the Conference of the Parties to the United Nations Framework Convention on Climate Change
CPO	crude palm oil
CST	concentrated solar thermal
DEA	Danish Energy Agency
DIE	German Development Institute
DLUC	direct land-use change
E20	20% ethanol blended with gasoline
EJ	exajoule
EnDev	Energising Development
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FPIC	Free, Prior and Informed Consent
FTP	Fast Track Program
ha	hectare
G20	Group of Twenty
gCO_2-eq	grams of carbon dioxide equivalent
GDE	Geo Dipa Energi, state-owned geothermal producer
GDP	gross domestic product
GFF	Geothermal Fund Facility
GIZ	German Agency for International Cooperation
GJ	gigajoule
GW	gigawatt
GWh	gigawatt-hour
IDR	Indonesian rupiah
IEA	International Energy Agency
ILUC	indirect land-use change
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISPO	Indonesian Sustainable Palm Oil
JAMALI	Java-Madura-Bali
KEN	National Energy Policy
kVDC	kilovolt direct current
kW	kilowatt
kWh	kilowatt-hour
LNG	liquefied natural gas
LPG	liquefied petroleum gas

LULUCF	land-use, land-use change and forestry
m^2	square metre
m^3	cubic metre
MEMR	Ministry of Energy and Mineral Resources
MJ	megajoule
Mha	million hectare
mBtu	million British thermal units
Mt	million tonne
MVA	megavolt amperes
MW	megawatt
MWh	megawatt-hour
n.d.	no date
NDC	Nationally Determined Contribution
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OTEC	Ocean Thermal Energy Conversion
PGE	Pertamina Geothermal Energy
PGN	Perusahaan Gas Negara, the largest natural gas transportation and distribution company in Indonesia
PJ	petajoule
PLN	Perusahaan Listrik Negara, the state electricity company
PM_{10}	particulate matter 10 micrometres or less in diameter
POME	palm oil mill effluent
PPA	power purchase agreement
ppp	purchasing power parity
PPU	private power utility
PSO	public service obligation
PV	photovoltaic
R&D	research and development
REDD	reducing emissions from deforestation and forest degradation
RIKEN	National Master Plan for Energy Conservation
RSPO	Roundtable for Sustainable Palm Oil
RUKN	National Electricity General Plan
RUPTL	Electricity Supply Business Plan
SNV	Not-for-profit international development organisation, based in the Netherlands
SO_2	sulphur dioxide
tscf	trillion standard cubic feet
TFEC	total final energy consumption
TPES	total primary energy supply
t CPO/ha/yr	tonne of crude palm oil per hectare per year
toe	tonne of oil equivalent
TWh	terawatt-hour
UNFCCC	United Nations Framework Convention on Climate Change
USAID-ICED	United States Agency for International Development – Indonesia Clean Energy Development
USD	United States dollar
VRE	variable renewable energy

EXECUTIVE SUMMARY

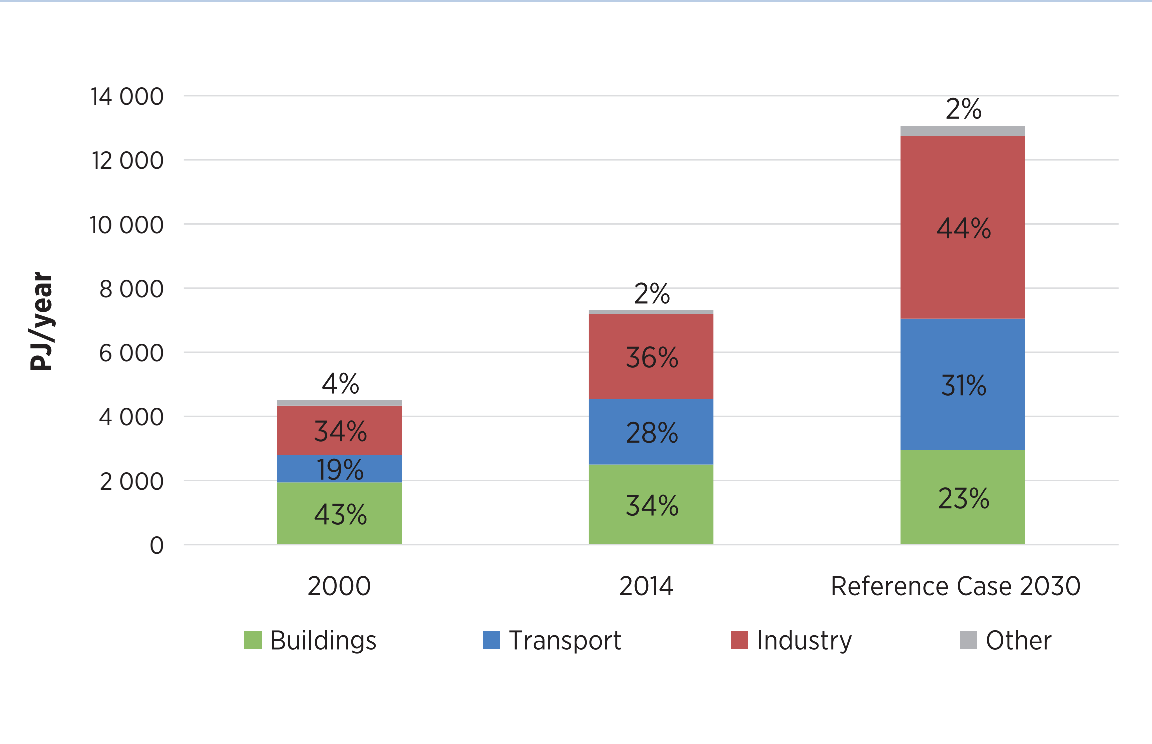
Rapid growth in energy consumption

Indonesia is among the world's fastest growing countries in terms of energy consumption. This is fuelled by robust economic development, increasing urbanisation and steady population growth. The country is the largest energy user in the Association of Southeast Asian Nations (ASEAN), accounting for nearly 40% of total energy use among ASEAN members. Between 2000 and 2014, energy consumption in Indonesia increased by nearly 65%. In a business-as-usual outlook (the "Reference Case" in this study), it is set to grow another 80% by 2030. Indonesia is therefore crucial to a renewable energy transition for the region as a whole.

Indonesia's electricity consumption will more than triple by 2030. Economic growth means rising use of electricity for cookers, fans, air conditioning and other appliances. At the same time, Indonesia is expanding electricity access in remote areas and islands. More than 10% of the country's population still lacks access to electricity, but the government is aiming for near-100% electrification by 2026.

Transport and industry show the fastest expected growth in energy use. For both sectors, energy consumption is expected to more than double between today and 2030. About 1 million motor vehicles and 7.5 million motorcycles and scooters are added to Indonesia's roads every year, further exacerbating the already severe air pollution in urban centres. Industrial energy use is expanding in line with economic growth, with large industries such as cement, aluminium, paper and ceramics accounting for a majority of the increase.

Figure ES1: Breakdown of total final energy consumption in Indonesia, 2000, 2014 and in the Reference Case for 2030



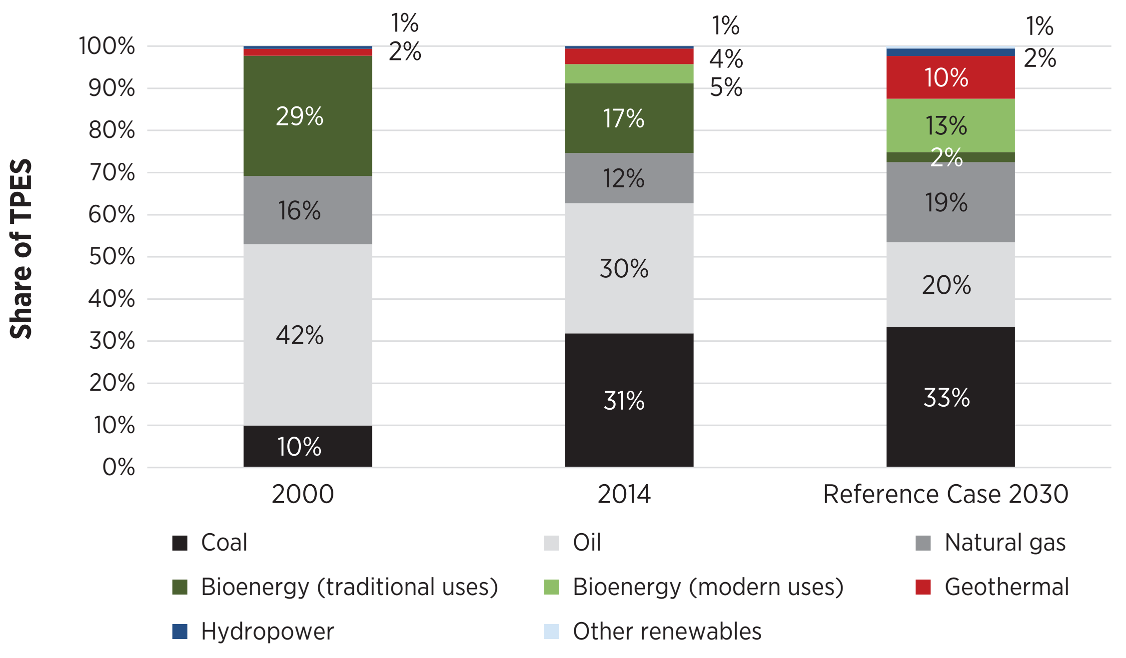
Sustainability concerns amid a changing energy supply mix

The use of coal is rising to meet domestic growth in energy demand. At the turn of this century, only about 10% of Indonesia's energy needs were met by coal. Currently, coal accounts for almost one-third of the energy supply. This rapid expansion is an outcome of government policy aimed at meeting high growth in energy demand while reducing imports of petroleum products. Indonesia is the fourth largest producer of coal worldwide and was the largest exporter in 2014. Coal increasingly is consumed domestically amid stagnant domestic production of natural gas and oil. Based on the Reference Case, the use of coal would more than double by 2030 from today's levels. This not only would mean additional greenhouse gas emissions from coal combustion, but it also would exacerbate air pollution and issues related to water contamination and scarcity.

Traditional uses of bioenergy dominate renewable energy use in Indonesia. A majority of renewable energy use in Indonesia is represented by traditional uses of bioenergy (mainly for cooking) in the country's rural areas and remote islands. Although the share of traditional bioenergy uses in the energy supply mix has declined, an estimated 24.5 million households (40% of all households) still rely primarily on fuelwood for cooking. This practice results in indoor air pollution which is associated with 165 000 premature deaths in Indonesia per year. In the Reference Case, mainly through the uptake of electricity and liquefied petroleum gas (LPG) for cooking, the number of houses relying on fuelwood would drop to about 8 million by 2030.

Liquid biofuel blending mandates – while advancing the transition to renewable energy sources – come with supply side challenges. Especially for transport, there is a strong projected increase in the use of liquid biofuels as a result of mandated biodiesel (B30) and ethanol (E20) blending from 2025 onwards. Total liquid biofuel use per year is projected to increase to 25 billion litres by 2030, compared to 1.35 billion litres of biodiesel that was blended in the first half of 2016. Today, biodiesel in Indonesia is produced from palm oil, a crop for which the government recently renewed a moratorium to prevent additional plantations.

Figure ES2: Fuel mix in primary energy supply, 2000, 2014 and in the Reference Case for 2030



Aiming for an affordable, secure and sustainable energy system

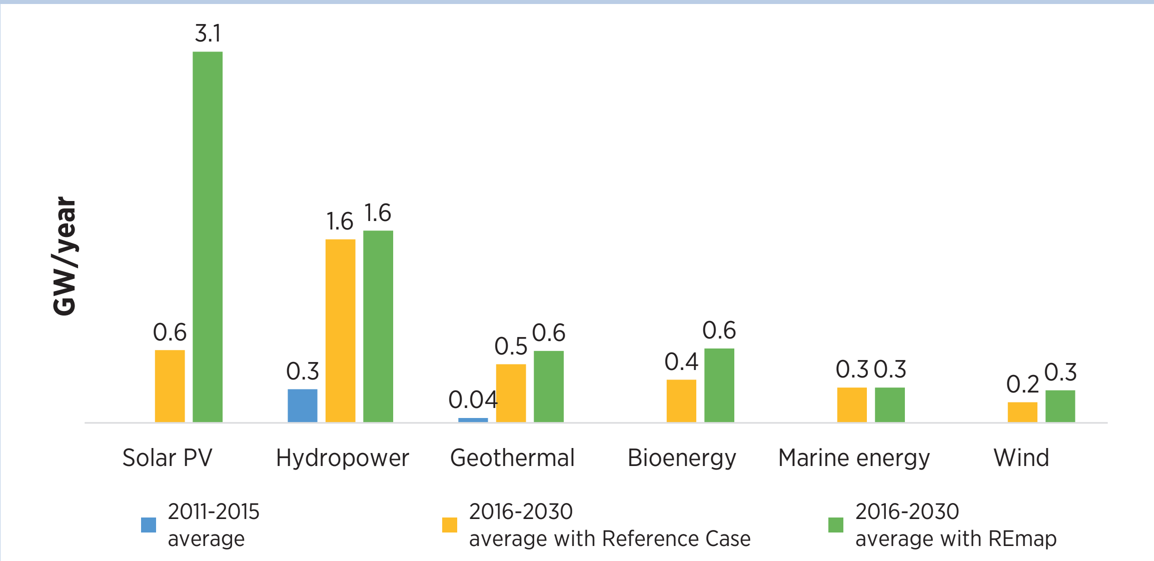
Indonesia already has ambitious targets to increase its use of renewable energy. The country has set an overall target to have modern renewables (excluding traditional uses of bioenergy) provide 23% of total primary energy supply (TPES) by 2025, and 31% by 2050. The Reference Case, which assumes that these targets are met, implies a share for renewable energy of 17% in total final energy consumption (TFEC) by 2030, up from about 6% today.

Indonesia could achieve its 2050 renewable energy targets two decades sooner. The International Renewable Energy Agency (IRENA) has worked with Indonesia's Ministry of Energy and Mineral Resources (MEMR) to develop a roadmap to 2030, highlighting ways to increase the uptake of renewable energy beyond the country's present policies and plans. Across sectors and technologies, the additional potentials ("REmap Options" in this study) increase the share of renewable energy to 23% of TFEC – or 31% of TPES – by 2030.

Renewable energy use will continue to be highest in power generation. In the Reference Case, the share of renewable energy in power generation would increase to 29% by 2030. To assess the potential for additional renewable power in Indonesia, five regions (Java-Bali, Kalimantan, Maluku & Papua, Sulawesi & Nusa Tenggara and Sumatra) were distinguished, and for each, the renewable resource potential and projected power demand in 2030 was analysed. Based on this assessment, the share of renewable energy in power generation increases to 38% by 2030 with the REmap Options.

Solar photovoltaics (PV) offers much greater potential than current plans for the power sector reflect. The REmap Options for hydropower, geothermal, bioenergy and wind power are modest, given their ambitious increase in the Reference Case and the geographical mismatch in resource potential and power demand. For solar PV, however, REmap identifies potential for 47 gigawatts (GW) of installed capacity by 2030, compared to just over 9 GW in the Reference Case. This includes plans to use solar PV to provide electricity to nearly 1.1 million households in remote areas that currently lack adequate access to electricity. Especially in Java-Bali (which accounts for 70% of power demand in Indonesia) there is enough available space, good infrastructure and additional need for power to greatly increase both rooftop and utility-scale solar PV installations.

Figure ES3: Annual installations of renewable power in 2011-2015, in the Reference Case for 2030 and with REmap

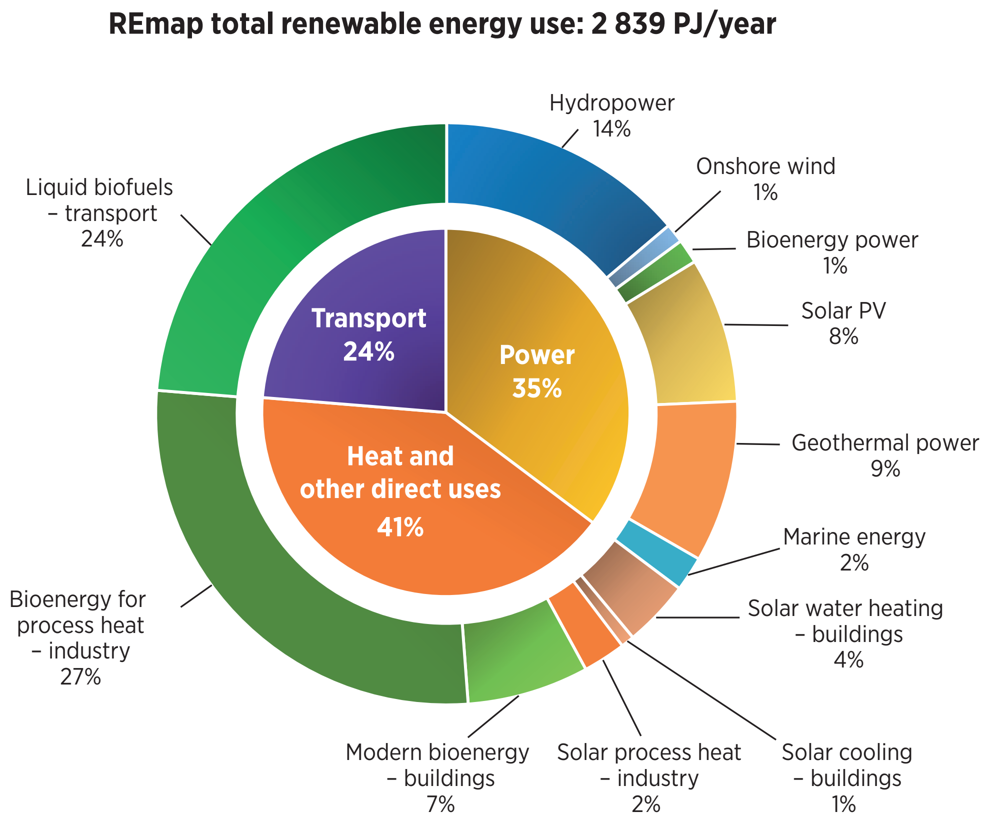


Next to power generation, Indonesia's greatest renewable energy use will be in buildings. Including the contribution of renewable electricity, the share of renewable energy in TFEC in buildings increases to 37% in 2030, compared to 18% in the Reference Case. With REmap, households that would rely on traditional uses of bioenergy for cooking in the Reference Case switch to modern cook stoves that use mostly solid biomass, and to some extent ethanol. Based on an assessment of available rooftop space and realistic deployment potential, solar thermal collectors supply 30% of energy used for water heating, while solar (thermal) cooling meets 5% of energy demand for cooling in buildings.

Industry will make much greater use of bioenergy and also could scale up solar thermal systems to supply process heat. Through the assessment of the projected energy use in key industry sectors and the supply potential of different types of feedstock, the REmap Options identify potential for an additional 216 petajoules (PJ) per year of bioenergy use in industry beyond the Reference Case. This consists of more use of biogas (from food waste and palm oil mill effluent), wood residues and waste. Combined with the identified potential of 70 PJ per year for solar thermal collectors to supply process heat (in the rubber, food and textile industries), the share of renewable energy in industry TFEC increases to 21% by 2030, compared to 15% by 2030 in the Reference Case and 12% in 2014.

Bioenergy will continue to play an important role in the use of renewables in Indonesia. With REmap, more than half of all renewable energy use in Indonesia in 2030 would be in the form of bioenergy used for process heat in industry or as liquid biofuels in transport. Solar applications (including PV and thermal) account for 15% of renewable energy use in all sectors in Indonesia as envisaged by REmap, followed by hydropower (14%) and geothermal power (9%).

Figure ES4: Breakdown of renewable energy in total final energy consumption in 2030 with REmap



Indonesia could have 3 million electric four-wheeled vehicles and 42.5 million electric two- and three-wheelers on the road by 2030. Given the high increase in the use of liquid biofuel in transport in the Reference Case and the associated supply-side constraints, the REmap Options in transport focus on electric mobility. With the continued increase in vehicle ownership, nearly 6% of all four-wheeled vehicles (consisting mainly of electric cars) and 20% of two- and three-wheelers would be electric by 2030. Combined, they increase the share of renewable energy in transport TFEC to 18%, from about 3% today.

Benefits of renewable energy greatly outweigh costs

Higher renewable energy uptake would reduce the total costs of the energy system. Based on a comparison of the cost of the REmap Options and the conventional fuels which they replace, the savings to the energy system in 2030 is estimated at USD 1.7 billion per year. This is from a government perspective, which excludes subsidies on energy prices and applies a discount rate of 10%. With a market discount rate of 12% and including energy subsidies, the additional costs to the energy system are USD 1.1 billion per year. This shows the importance of further removing energy subsidies, such as on prices for electricity and selected petroleum products, as well as of lowering the cost of capital for renewable energy projects.

Renewable energy can strengthen Indonesia's energy security while greatly reducing emissions. The REmap Options reduce demand for fossil fuels by 10% relative to the Reference Case. The impact is the largest for coal (-17%) and oil (-9%) and thus would contribute to reducing imports of petroleum products, which have increased in recent years. The reduction in the use of coal, which is projected to increase in most ASEAN countries, contributes strongly to avoided carbon dioxide (CO_2) emissions with REmap, which are 150 million tonnes (Mt) per year lower than with the Reference Case.

Indonesia needs to focus more on energy efficiency and on non-energy emissions in order to achieve its Nationally Determined Contribution (NDC) in the global effort to address climate change. Indonesia's NDC aims for a 29% (unconditional) reduction in greenhouse gas emissions by 2030 compared to a business-as-usual scenario. The REmap Options would account for about half of the targeted energy-related reductions. However, the business-as-usual scenario used to determine the NDC can be considered conservative, as it does not include any renewable energy deployment or energy efficiency improvements. Furthermore, forestry accounts for more than half of Indonesia's overall targeted unconditional reductions. Therefore, reducing emissions through further energy efficiency improvements and in other sectors – particularly from land use, land-use change and forestry (LULUCF) – will be crucial as well.

Scaling up renewables can save Indonesia between USD 15.6 billion and USD 51.7 billion per year when the impacts on air pollution and climate change are included. With REmap, the avoidance of premature deaths and the savings that come with reduced health costs from reductions in outdoor air pollution are valued at USD 3.0 billion to USD 9.7 billion per year. Reduced externalities from indoor air pollution account for another USD 10.4 billion to USD 31.3 billion per year, due to the substitution of traditional uses of bioenergy for cooking. As said, the REmap Options also would lead to a reduction of 150 Mt of CO_2 emissions per year which, with a carbon price of USD 17 to USD 80 per tonne equates to savings of USD 2.2 billion to USD 10.7 billion per year in 2030. The reduced system costs and externality savings equal 0.5% to 1.7% of Indonesia's forecasted gross domestic product in 2030.

Greater renewable energy deployment will create more jobs and stimulate technology transfer. Earlier IRENA work has indicated the potential for 1.3 million jobs in the renewable energy sector in Indonesia by 2030, up from just over 100 000 today. Scaling up the market for renewable energy technologies provides significant opportunities for localising parts of the value chain, such as through local manufacture of solar panels and electric vehicles, with the associated technology transfer having the potential to come with additional positive effects to the economy.

Investments in renewable energy need to accelerate rapidly in Indonesia. Annual investment in renewable energy capacity in the Reference Case is estimated at, on average, USD 9.4 billion in 2015-2030. With the REmap Options this would increase to USD 16.2 billion. The power sector accounts for USD 13.2 billion, nearly half of which is for solar PV. Given the modest level of investments today, a rapid acceleration is required for Indonesia to capture its renewable energy potential.

Challenges in accelerating renewable energy deployment

For Indonesia to accelerate its uptake of renewable energy, several challenges have to be addressed. These challenges are different for the power sector and for the energy end-use sectors of transport, buildings and industry. Bioenergy, given its cross-cutting application across sectors and technologies, warrants its own assessment.

In the power sector, several broad barriers are evident, along with technology-specific challenges:

- Grid integration of variable renewable energy (VRE) might come with challenges given the highly fragmented nature of Indonesia's grid, with many small grids in remote locations;
- For off-grid areas there is a lack of bankable off-takers, the risk of inadequate system design, and operational issues due to the insufficient operation and maintenance (O&M) of systems;
- Cost recovery for PLN (the national utility) remains an issue as feed-in tariffs for renewable energy generally exceed the price that PLN charges to consumers of electricity; however, a recent Ministerial Degree will affect feed-in tariff pricing and limit renewable energy tariffs to between 85% and 100% of PLN's regional production price;
- Project finance opportunities for renewable energy projects in Indonesia are limited at present, as local banks do not allocate sufficient resources to this segment;
- Land acquisition issues are common due to a lack of clarity regarding land ownership in many locations, while the process for acquiring land is often costly and time consuming;
- Technology-specific challenges (*e.g.*, for solar PV, wind, etc.) include a lack of awareness of solutions, the need to build local capacity, a lack of streamlined permitting and regulatory frameworks, and the absence of detailed resource assessments.

In the end-use sectors, Indonesia needs to address key challenges as well:

- Solar thermal for water heating and cooling in buildings has great potential; however, limited awareness of solutions and a lack of design standards are holding back the market;
- Limited awareness in industry of the potential for solar collectors to supply process heat and their intermittent supply of energy pose barriers, as well as space limitations which might be an issue for existing plants;
- The focus for renewable energy in transport is on liquid biofuels, whereas electric mobility remains largely unaddressed. A lack of infrastructure and regulatory frameworks is holding back the identified potential for electric four-wheeled vehicles and two-and-three wheelers.

Challenges can arise for bioenergy on both the supply and demand sides. Concerns about the sustainability of supply, despite the potential of yield improvements and the use of degraded lands, pose a challenge to Indonesia's targets for liquid biofuel blending. In industry, the potential of using residues and waste comes with the challenges of high transportation cost, seasonality of feedstock supply, the lack of a local grid to interconnect (power) projects, and competition for the feedstock with other uses (*e.g.*, the use of trunks and leaves to replenish soil). The accelerated use of modern cook stoves – using solid biomass and ethanol instead of traditional uses of bioenergy for cooking – is challenged by limited awareness and high required upfront investment.

Areas for action

Various solutions are available to promote higher uptake of renewable energy in Indonesia. These can be grouped into three main areas for action:

1. **Intensify efforts to meet the growing demand for electricity by capturing the full potential of Indonesia's vast renewable energy resources.**

Indonesia is endowed with phenomenal resources for renewable power generation. To capture the country's potential and address the existing challenges, Indonesia's policy makers and energy decision makers are encouraged to:

- Align the targets for renewable energy deployment among different stakeholders and incorporate the expected deployment of VRE in transmission and distribution plans. Consider using energy storage to smooth integration of VRE and introduce priority dispatch for renewable energy generation.
- Identify funds that can cover the gap between renewable energy power purchase agreements (PPAs) and the revenues that PLN receives from consumers. The process for PLN to negotiate PPAs directly with developers for projects should be more standardised and should include more detailed requirements.
- Establish larger off-grid working areas encompassing multiple villages to achieve economies of scale for off-grid solutions, and consider expanding PLN's responsibilities to build and own distribution networks in off-grid locations to further reduce the cost to off-grid solution providers. Create an entity responsible for overseeing O&M of mini-grid systems – involving local communities – and expand the use of standardised survey methodologies to ensure that systems are scaled adequately.
- Increase awareness of opportunities among commercial banks and send clear signals that renewables will receive long-term, stable policy support. Create standard procedures and performance indicators for project development documents.
- Involve local communities early in the project development phase and consider providing additional services from projects (such as providing electricity) to communities. Large regional differences in the cost of land should be reflected more in feed-in tariffs, and the government could take a more active role in providing lands for projects.
- Address other barriers specific to each of the renewable power technologies – which consist mainly of increasing awareness and local capacity building and maximising local value; streamlining permitting and regulatory frameworks; and expanding resource assessments.

2. **Increase the focus on renewable energy opportunities in industry, buildings and transport.**

To fully capture the potential of renewable energy to reduce emissions and air pollution, more attention to these end-use sectors is recommended. Here, Indonesia has several options:

- Consider requirements for solar water heater installations in building codes and demonstration projects for solar cooling technologies.
- Highlight the potential for solar thermal energy to substitute for petroleum products, for example through local demonstration projects. Consider solar thermal storage capacity and/or hybrid solutions in the design and construction of new industrial plants.
- Combine infrastructure investments (such as charging infrastructure at large parking lots in cities) with support policies (*e.g.*, tax exemptions) to expand the market for electric vehicles and electric two- and three-wheelers. Electric mobility, when powered by renewable energy, could play an important role in reducing air pollution in cities and in reducing the reliance on liquid fuels in transport. Policy support for electric mobility is crucial given the immaturity of the market in Indonesia and the relatively high cost compared to conventional cars and electric two- and three-wheelers.

3. Develop an integrated and comprehensive bioenergy programme that captures Indonesia's potential and ensures its use in a sustainable manner.

Indonesia's abundant resources for bioenergy can be used in multiple applications spanning all economic sectors. The detailed recommendations provided in the report include this key suggestion:

- Develop a comprehensive bioenergy programme with the objective of maximising the sustainable use of the local resource through gradually increasing targets across sectors. Innovative approaches and technologies on both the supply side and demand side should be included, while the sustainability of bioenergy use in Indonesia should be safeguarded. Solutions with a high impact and low cost should be prioritised. One example is increasing the use of biogas produced from palm oil mill effluent, which not only was found to be a cost-competitive option, but also avoids methane emissions that occur when the biogas is not used. The efforts of the Indonesia Clean Stove Initiative and the Indonesia Domestic Biogas Programme also should be expanded to advance the dissemination of modern cook stoves based on bioenergy.

1 THE REMAP PROGRAMME AND REMAP INDONESIA

1.1 IRENA's REmap programme

The REmap programme aims to pave the way to promoting accelerated renewable energy development through a series of activities including global, regional and country studies. REmap analysis and activity also informs IRENA publications on specific renewable technologies or energy sectors.

The REmap programme collaborates closely with governmental bodies and other institutions which are responsible for energy planning and renewable energy development. The analysis relies on broad consultations with energy experts and stakeholders from numerous countries around the world.

At its inception, REmap emerged as IRENA's proposal for a pathway to support the United Nations Sustainable Energy for All initiative in its objective to double the global share of renewable energy from 18% in 2010 to 36% by 2030 (UN and World Bank, 2016). Since then, the Paris Agreement was adopted at COP21 in 2015 with a target of minimising the earth's temperature increase to below 2 degrees Celsius (°C) by 2050. The widespread development of renewables is a critical lever to fulfilling this objective.

To double the renewable energy share across the world, REmap takes a bottom-up approach. Country-level assessments are carried out to determine the potential contributions that each country could make to the overall renewable energy share. The first global REmap report, published in 2014, included a detailed analysis of 26 major energy-consuming countries representing around 75% of global energy demand. The REmap programme has since expanded to 40 countries accounting for 80% of world energy use.

The REmap evaluation of the national plans of 40 countries (which could be considered the business-as-usual case) suggests that under current conditions and policy approaches, the global share of renewables increases to only 21%. This indicates a 15 percentage-point shortfall in relation to the target to double the global renewables share by 2030 (IRENA, 2016a). Indonesia's role will be crucial to accelerate broader regional renewable energy deployment, given that it is the largest energy user in the Association of Southeast Asian Nations (ASEAN)[1].

In 2015, Indonesia set a target for the country to realise 23% of primary energy supply from modern renewable energy by 2025, as part of a collective target set by ASEAN member states. Because Indonesia is the largest country in ASEAN, understanding the role of renewables to meet the country's growing energy demand is key for the region. With a population of more than 250 million spread out over more than 17000 islands, Indonesia faces challenges today in matching energy demand and supply. The largest demand centres are Java and Sumatra in the west, whereas the main energy resources are in Kalimantan and the eastern provinces. Electrification is on the rise in Indonesia, from 65% in 2008 to 80.5% in 2013. However, large differences exist across the country, from less than 40% electrification in Papua to close to 100% in Jakarta. Indonesia's state utility company PLN (Perusahaan Listrik Negara) aims for 98% electrification by 2022.

While plans exist to expand interconnection, transmission bottlenecks and isolated areas remain constraints to optimising Indonesia's energy system and the role of renewables therein. Ambitious fuel support schemes and mandates were introduced in the transport sector, but results are falling short of ambitions. With energy demand increasing rapidly, expanding the share of modern renewable energy will be challenging given the country's infrastructure constraints and its decreasing reliance on traditional biomass. However, the drivers are clear: positive impacts in terms of socio-economics, public health, and the environment, as well as energy

1 ASEAN member countries are Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Viet Nam.

security and technology development, all support an increase in the use of renewables in Indonesia.

In January 2016, Indonesia approached the International Renewable Energy Agency (IRENA) to start a collaboration in preparation of a specific renewable energy roadmap (REmap) report for the country, with the desire to develop a practical roadmap that clearly identifies technology potentials and shows how implementation gaps can be closed for Indonesia to reach its renewable energy ambitions. IRENA's REmap work assesses the potential, costs and benefits of renewables beyond national targets and plans of countries at a sector level. REmap is based on close co-operation and consultation with country experts nominated by each government. It does not investigate multiple scenarios for the future, but instead focuses on technology options.

Indonesia has been a part of the REmap programme since 2013, and the work that was completed prior to the current study was used as a starting point for the present REmap Indonesia report. For REmap Indonesia, the government highlighted a particular interest in the following topics: empowering renewables in isolated settings (given the island structure of Indonesia), integrating variable renewable energy (VRE) generation and ensuing grid limitations, the potential and approach for utilising renewables in end-use sectors, and the opportunities for expanding the use of biofuels. The overall objective is to identify how Indonesia can achieve its ambitions for increasing the share of modern renewables. Costs, benefits and potentials per technology on a sectoral level, and clear policy recommendations and focus areas for Indonesia are provided.

1.2 The REmap approach

This section explains the REmap methodology and summarises the background data used for the Indonesia analysis. The annexes provide more detailed information.

REmap is a roadmap of technology options to increase the global share of renewables. It involves a bottom-up, iterative analysis. By March 2016, IRENA's REmap programme had assessed the potential for renewables in 2030 of 40 countries, which would account for 80% of total global energy demand. These are: Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, Ethiopia, France, Germany, India, **Indonesia**, Iran, Italy, Japan, Kazakhstan, Kenya, Kuwait, Malaysia, Mexico, Morocco, Nigeria, Poland, the Republic of Korea, the Russian Federation, Saudi Arabia, South Africa, Sweden, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States and Uruguay.

REmap identifies the realistic potential for accelerating renewable energy deployment. This can be fulfilled with existing technologies and is economically practical and achievable by 2030.

The REmap analysis starts by building the energy balance of a country, using 2010 as the base year of the analysis, based on national data and statistics. To the extent that data availability allows, information for more recent years (in the case of Indonesia, for 2014) is provided where relevant. The country then provides its latest national energy plans and targets for renewables and fossil fuels, collated to produce a business-as-usual perspective of the energy system, referred to as the **Reference Case.** This includes total final energy consumption (TFEC) for each end-use sector (buildings, industry and transport) and distinguishes between power, district heating and direct uses of energy with a breakdown by energy carrier for the period 2010-2030.

Once the Reference Case is ready, the additional renewable energy potential by technology is investigated for each sector. The potential of these technologies is described as **REmap Options**[2]. Each REmap Option replaces a non-renewable energy technology[3] to deliver the same energy service. The resulting case when all of these options are aggregated is called **REmap.**

Throughout this study, the renewable energy share is estimated in relation to TFEC[4]. Modern renewable

2 An approach based on options rather than scenarios is deliberate. REmap is an exploratory study and not a target-setting exercise.

3 Non-renewable technologies encompass fossil fuels, non-sustainable uses of bioenergy (referred to here as traditional bioenergy) and nuclear power. As a supplement to this report's annexes, a detailed list of these technologies and related background data are provided on the REmap website.

4 TFEC is the energy delivered to consumers as electricity, heat or fuels that can be used directly as a source of energy. This consumption is usually subdivided into transport, industry, residential, commercial and public buildings, and agriculture. It excludes non-energy uses of fuels.

energy excludes traditional uses of bioenergy[5]. The share of modern renewable energy in TFEC is equal to total modern renewable energy consumption in end-use sectors (including consumption of renewable electricity and district heat, and direct uses of renewables), divided by TFEC. The share of renewables in power generation also is calculated. The renewable energy share also can be expressed in terms of the direct uses of renewables only. The renewable energy use by end-use sector covers the areas described below.

- **Buildings** include the residential, commercial and public sectors. Renewable energy is used in direct applications for heating, cooling or cooking purposes or as renewable electricity.
- **Industry** includes the manufacturing and mining sectors, in which renewable energy is consumed in direct-use applications (*e.g.,* process heat or refrigeration) and electricity from renewable sources.
- **Transport** sector, which can make direct use of renewables through the consumption of liquid and gaseous biofuels or through electricity generated using renewable energy technologies.

Metrics for assessing REmap Options

To assess the costs of REmap Options, **substitution costs** are calculated. This report also discusses the costs and savings of renewable energy deployment and related externalities due to climate change and air pollution. Experts devised four main indicators: **substitution costs**, **system costs**, **total investment needs** and **needs for renewable energy investment support**.

Substitution costs

Each renewable and non-renewable technology has its own individual cost relative to the non-renewable energy that it replaces. This is explained in detail in the REmap methodology (IRENA, 2014a) and is depicted in the following equation:

$$\text{Cost of Technology/REmap Options (USD/year in 2030)} = \text{Equivalent annual capital expenditure (USD/year in 2030)} + \text{Operating expenditure (USD/year in 2030)} + \text{Fuel cost (USD/year in 2030)}$$

For each REmap Option, the analysis considers the cost of substituting a non-renewable energy technology to deliver an identical amount of heat, electricity or energy service. The cost of each REmap Option is represented by its **substitution cost**[6,7]:

$$\text{Substitution cost (USD/GJ in 2030)} = \frac{\text{Cost of REmap Options (USD/year in 2030)} - \text{Cost of substituted conventional technology (USD/year in 2030)}}{\text{Energy substituted by REmap Options (GJ/year in 2030)}}$$

This indicator provides a comparable metric for all renewable energy technologies identified in each sector. Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (additional) or negative (savings) because many renewable energy technologies are or could by 2030 be more cost-effective than conventional technologies.

System costs

On the basis of the substitution cost, inferences can be made as to the effect on **system costs.** This indicator is the sum of the differences between the total capital and operating expenditures of all energy technologies based on their deployment in REmap and the Reference Case in 2030.

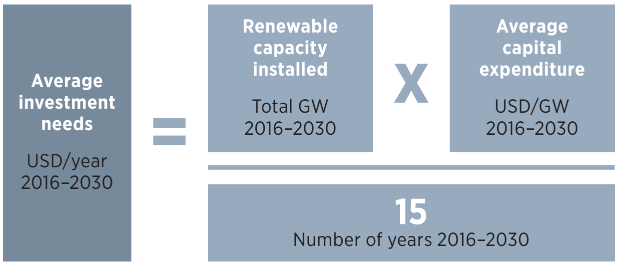
5 The Food and Agriculture Organization of the United Nations (FAO) defines traditional biomass use as woodfuels, agricultural by-products and dung burned for cooking and heating purposes (FAO, 2000). In developing countries, traditional biomass is still widely harvested and used in an unsustainable, inefficient and unsafe way. It is mostly traded informally and non-commercially. Modern biomass, by contrast, is produced in a sustainable manner from solid wastes and residues from agriculture and forestry and relies on more efficient methods (IEA and World Bank, 2015).

6 Substitution cost is the difference between the annualised cost of the REmap Option and the annualised cost of the substituted non-renewable technology used to produce the same amount of energy. This is divided by the total renewable energy use substituted by the REmap Option.

7 1 gigajoule (GJ) = 0.0238 tonnes of oil equivalent (toe) = 0.238 gigacalories = 278 kilowatt-hours (kWh); USD 1 was on average equivalent to IDR 13 500 in the first half of 2016.

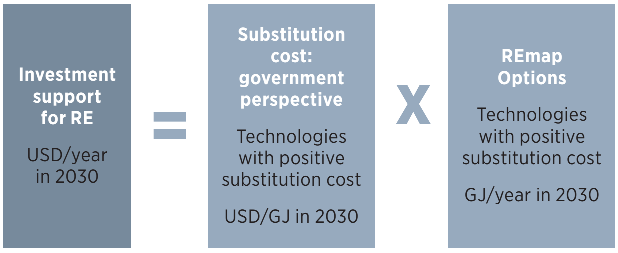
Investment needs

Investment needs for renewable energy capacity also can be assessed. The total **investment needs** of technologies in REmap are higher than in the Reference Case due to the increased share of renewables. On average, these have greater investment needs than the non-renewable energy technology equivalent. The capital investment cost in USD per kilowatt (kW) of installed capacity in each year is multiplied with the deployment in that year to arrive at total annual investment costs. The capital investment costs of each year are then added up for the period 2016-2030. Net incremental investment needs are the sum of the differences between the total investment costs for all renewable and non-renewable energy technologies in power generation and stationary applications in REmap and the Reference Case in the period 2016-2030 for each year. This total was then turned into an annual average for the period.



Renewable energy investment support needs

Renewable energy investment support needs also can be approximated on the basis of the REmap tool. Total requirements for renewable investment support in all sectors are estimated as the difference in the delivered energy service cost (*e.g.*, in USD per kWh or USD per GJ from a government perspective) for the renewable option against the dominant incumbent in 2030. This difference is multiplied by the deployment for that option in that year to arrive at an investment support total for that technology. The differences for all REmap Options are added together to provide an annual investment support requirement for renewables. The renewable option is not subtracted from the total if it has a lower delivered energy service cost than the incumbent option. By 2030, this is an increasing trend.



Government and business perspectives

Based on the substitution cost and the potential of each REmap Option, country cost-supply curves are developed for 2030 from two perspectives: **government** and **business.**

- **Government perspective:** cost estimates exclude energy taxes and subsidies. In the latest global REmap study (IRENA, 2016a), a standard discount rate of 10% (for non-OECD countries) or 7.5% (for OECD countries) was used. This approach allows a comparison across countries and a country cost-benefit analysis; it shows the cost of the transition as governments would calculate it.
- **Business perspective:** this considers national prices (including, for example, energy taxes, subsidies and the cost of capital) in order to generate a localised cost curve. This approach shows the cost of the transition as businesses or investors would calculate it. A discount rate of 12% is assumed in the case of Indonesia.

By estimating the costs from two perspectives, the analysis shows the effects of accounting for energy taxes and subsidies while all other parameters are kept the same. An assessment of all additional costs related to complementary infrastructure (*e.g.*, grid reinforcements, fuel stations) is excluded from this report. IRENA analysis suggests that these would be of secondary importance to countries only just embarking on their energy system transformation.

Externality analysis

Several externality reductions obtained through REmap Options are considered. They include health effects from outdoor or indoor exposure to pollution in the case of traditional bioenergy, as well as effects on agricultural yields. In addition, the external costs associated with the social and economic impacts of carbon dioxide (CO_2) are estimated (IRENA, 2016a).

Further documentation and a detailed description of the REmap methodology can be found at *www.irena.org/remap.* Further details on metrics for assessing REmap Options can be consulted in the appendix of the 2016 global report (IRENA, 2016a).

1.3 Main sources of information and assumptions

The following key sources have been used to prepare the base year for the Indonesia analysis (2014), the Reference Case for 2030 and the REmap Options:

- **Base year 2014:** The starting point of the analysis is Indonesia's energy balance for 2014. The data are based on the *Handbook of Energy & Economic Statistics of Indonesia*, as prepared by the Indonesian Ministry of Energy and Mineral Resources (MEMR, 2015). The same document and previous editions also are used to estimate historical trends in energy demand and supply.
- **Reference Case:** The Reference Case for Indonesia is based on three main sources:
  - The National Energy Policy (KEN) scenario of the Energy Outlook Indonesia 2014 was used to generate a business-as-usual outlook for total final energy consumption and the breakdown of fuels consumed therein (MEMR, 2014a).
  - The National Electricity General Plan (RUKN) 2015-2034 was used for the Reference Case for the power sector, whereby Indonesia was split into five regions: Java-Bali, Kalimantan, Maluku & Papua, Sulawesi & Nusa Tenggara and Sumatra (MEMR, 2016a). The revised KEN 2025 targets for the various renewable power technologies were used to derive estimates for the installed power capacity for each by 2030.
  - Finally, as the RUKN power generation target for 2030 exceeds the power generation target that is included with the KEN scenario of the Energy Outlook Indonesia 2014, TFEC estimates from the latter were increased, reflecting higher growth in overall energy demand and a higher share of electricity in energy use.
- **REmap:** This is based on IRENA's analysis combined with existing literature on Indonesia and information obtained through the REmap Indonesia kick-off workshop that was held in Jakarta on 1 April 2016. For the power sector the analysis for estimating the additional potentials for renewable generation and capacity are based on analysis of the above-mentioned five regions.

Finally, energy supply and demand numbers in this report generally are provided in petajoules (PJ) or exajoules (EJ), the standard for REmap. In Indonesia, commonly used units are tonnes of oil equivalent (toe). The relevant conversion factors are listed below:

- 1 GJ = 0.0238 toe
- 1 GJ = 277.78 kilowatt-hour (kWh)
- 1 PJ = 0.0238 million toe
- 1 PJ = 277.78 gigawatt-hour (GWh)
- 1 EJ = 23.88 million toe
- 1 EJ = 277.78 terawatt-hour (TWh)

This report is structured as follows: Chapter 2 introduces the overall energy and power sector context in Indonesia and presents the main renewable energy developments so far. Chapter 3 provides an overview of the current policy framework. Chapter 4 describes the renewable energy developments in the Reference Case. Chapter 5 describes the potential and costs of renewable energy in Indonesia. Chapter 6 discusses the REmap Options, including their cost and benefits. Chapter 7 includes a discussion on the key barriers and opportunities in Indonesia to achieve the REmap Options. Chapter 8 provides key recommendations for a larger renewable energy uptake.

2. CURRENT SITUATION AND RECENT TRENDS

Key points

- Indonesia accounts for nearly 40% of TFEC in the ASEAN region. Indonesia's TFEC equalled 7.3 EJ in 2014 across the country's more than 17 000 islands. Across sectors and applications, energy use in Indonesia is growing rapidly. Between 2010 and 2014, TFEC increased by more than 20%, while power generation increased by 35%. Java-Bali accounts for more than half of TFEC today.

- Renewable energy use in Indonesia is dominated by bioenergy use in end-use sectors (industry, buildings and transport). Traditional uses of bioenergy (mainly for household cooking) account for 80% of total renewable energy use. Modern renewable energy use (excluding traditional uses of bioenergy) was 426 PJ in 2014, equivalent to 5.8% of TFEC. With traditional uses of bioenergy included, renewable energy use in 2014 was 2 046 PJ or 28% of TFEC.

- Bioenergy use in industry represents the majority of modern renewable energy use in Indonesia today, at about 65% of the total, followed by the use of biodiesel in transportation (13%). Renewables in power generation contribute the remaining 22%, of which hydropower (15 TWh per year), geothermal power (10 TWh per year) and bioenergy (5 TWh per year) accounted for nearly all. The share of renewable power in total power generation was 12.4% in 2014.

- Drivers for expanding the renewable energy base in Indonesia are manifold. Such expansion would have significant positive effects on human health and the environment through the reduction of air and water pollution from mining and burning coal (and other fossil fuels). Positive macro-economic impacts include the creation of jobs and the positive impact on gross domestic product (GDP) of using more renewable energy. Imports of petroleum products, which have been increasing in recent years, could be reduced, increasing energy security. Finally, renewable energy can be used to increase energy access, mainly through the use of solar photovoltaics (PV) and small-scale hydropower in remote locations.

2.1 Indonesia's energy system and recent developments in renewable energy

Energy consumption

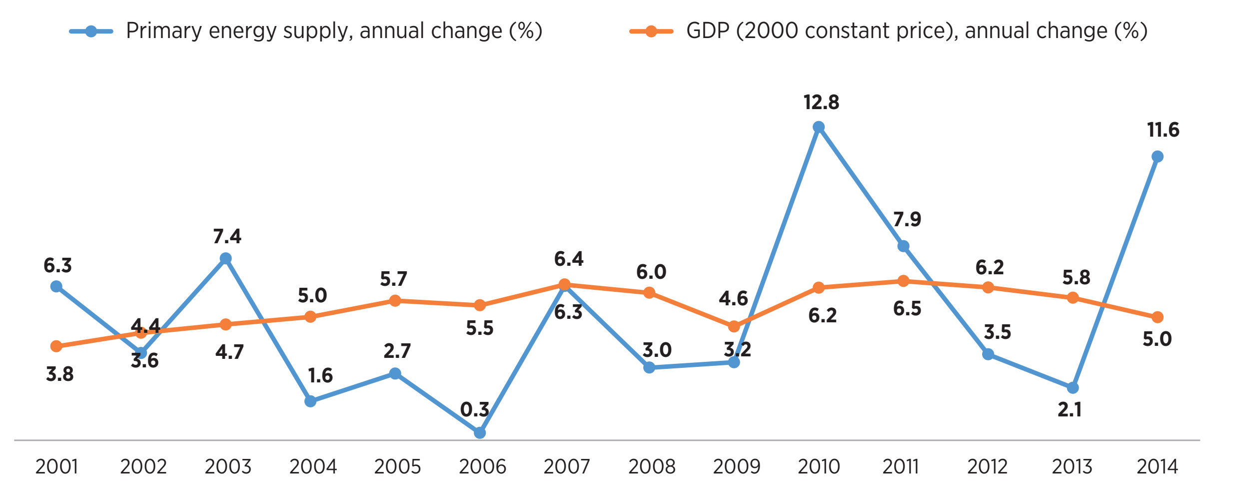
Indonesia is the largest energy user in the ASEAN region, accounting for 38% of TFEC in 2013 (ACE, 2015a). Across more than 17 000 islands, TFEC in Indonesia amounted to 7.3 EJ in 2014 (excluding non-energy use), an increase of just over 20% since 2010 (MEMR, 2015). Longer term, the growth in energy consumption in Indonesia is closely related to economic growth (see figure 1).

More than half of all modern energy consumption (excluding traditional uses of bioenergy) in Indonesia takes place on Java, in line with the island's share of the Indonesian population (see figure 2). Sumatra follows with one-quarter of energy consumption, and the other islands account for the remaining 19%.

Energy supply mix

Petroleum products (diesel, gasoline and liquefied petroleum gas – LPG) accounted for the largest share of TFEC in 2014, at 37% (or 2.7 EJ), down from 40% in 2010 (see figure 3). The most important reason for the declining share is the increasing reliance on coal, due in part to a range of government policies over the past years in support of the domestic coal industry (EIA, 2015). Coal use therefore showed the largest increase between 2010 and 2014: from 0.8 EJ or 14% of TFEC in 2010, to 1.4 EJ or 18% of TFEC in 2014. Bioenergy (including traditional uses) had the second largest share in TFEC in 2014, at close to 27 % (equivalent to

Figure 1: Growth in GDP and primary energy supply in Indonesia, 2001-2014

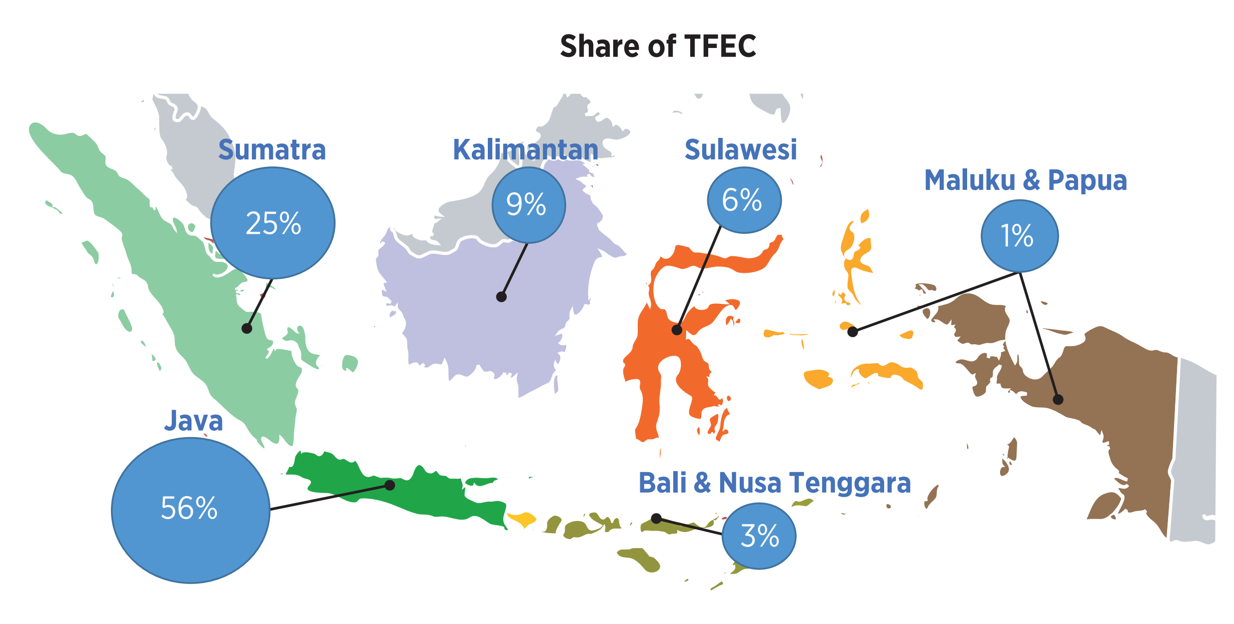


Source: MEMR, 2015

total demand of 2.0 EJ), a vast majority of which was consumed in buildings (83%, mainly in the form of fuelwood for cooking), followed by industry (14%) and transport (3%). Since 2010, the share of bioenergy has remained at the same level, although in the longer term its share is decreasing.

Between 2010 and 2014, electricity consumption increased by 34%. Its share of TFEC went up slightly in the same period, from 9% to 10%, still representing a low share compared to the level in developed economies at around 30% (the global average was 22% in 2013). About two-thirds of electricity is consumed in buildings,

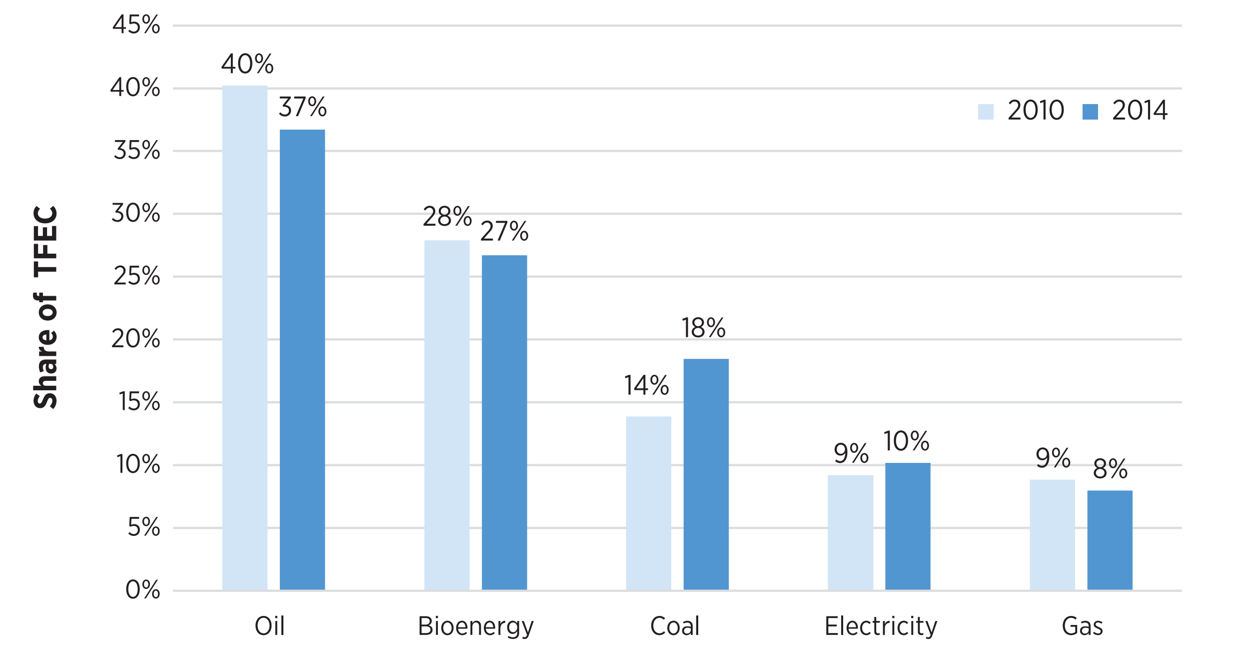
Figure 2: Breakdown of total final energy consumption in Indonesia, 2013



Note: excluding traditional use of bioenergy

Source: IRENA analysis and MEMR, 2015

Figure 3: Breakdown of final energy consumption by carrier in Indonesia, 2010 and 2014



Source: IRENA analysis and MEMR, 2015

and about one-third in industry. The electrification rate was 88% in 2015, with a target of 97% for 2019 (MEMR, 2016a). Finally, natural gas use went up in recent years, but its share in the overall energy mix declined: from 0.5 EJ or 9% in 2010 to 0.6 EJ or 8% in 2014.

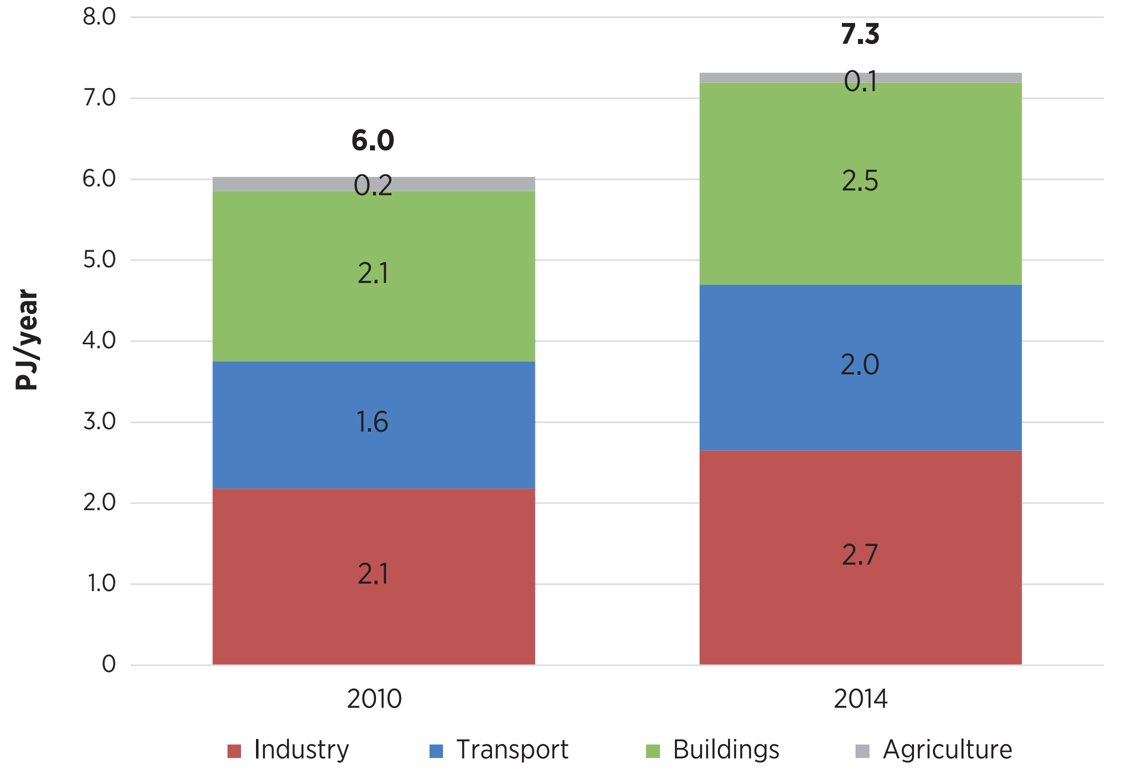
The share of renewable energy (including traditional biomass) in Indonesia's TFEC has decreased greatly since the turn of the century: from 59% in 2000 to 37% in 2013 (IRENA, 2016a). This is due to the increasing reliance on modern forms of energy – based mainly on fossil fuel burning – in meeting growing energy demand, while the share of bioenergy is declining over time.

Buildings

Buildings (residential, commercial and public) account for more than one-third of Indonesia's TFEC, at 2.5 EJ in 2014 (see figure 4). Although building energy demand has increased nearly 20% since 2010, its share in TFEC showed little change. Nearly 90% of building energy demand is consumed by households, with another 10% used in commercial buildings. As in the rest of Southeast Asia, cooking represents a majority of household energy use in Indonesia and is estimated to account for more than 80% of total residential energy demand (Daioglou *et al.*, 2012). The remaining 20% is split between space cooling, water heating, appliances and lighting. In the commercial sector the split is different: half of energy demand is used for space cooling, with another 30% for appliances and lighting and the remaining 10% for cooking and water heating.

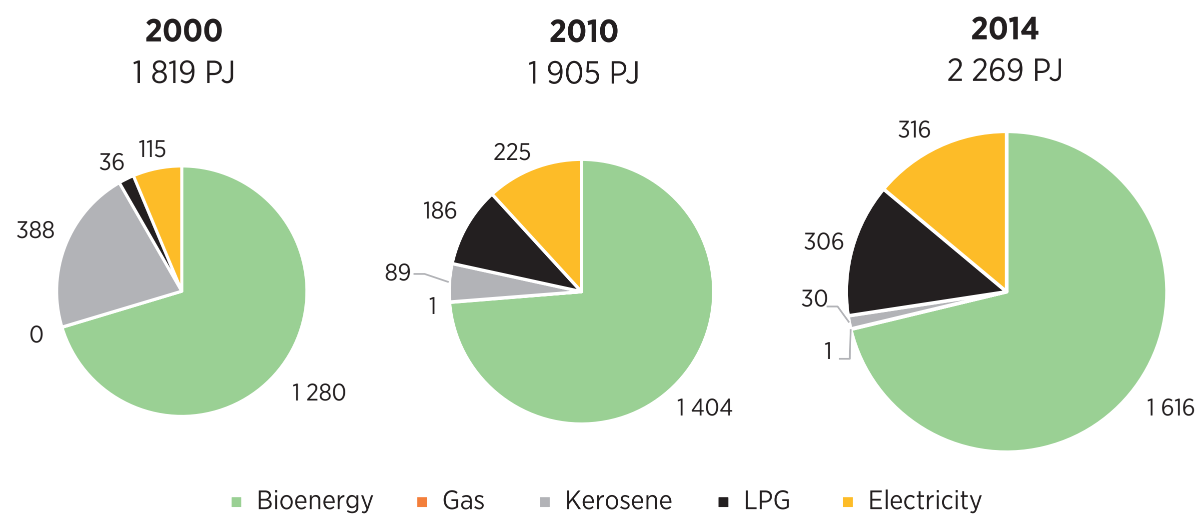
Since 2000 the number of households in Indonesia has increased by about 1.5% per year – to nearly 65 million by the end of 2014 – with a constant average of around four people per household. Interestingly, energy consumption per household also stayed constant over the period, at around 10 MWh per household per year. The constant level of final energy demand per household in Indonesia is not an outcome of a stagnating appetite for energy, but rather is explained by the changing composition of the fuel mix, with a transition to more efficient forms of energy use (see figure 5). Kerosene, used mainly for cooking in Indonesia, had a share of over 20% in residential TFEC in 2000. In recent years it was substituted on a large scale by LPG due to the phasing out of fuel subsidies and a large-scale conversion programme by the Indonesian government (PLN and WLPGA, 2015). LPG, which is estimated to be about 40% to 60% more efficient for cooking than kerosene, accounted for 13% of residential energy use in Indonesia in 2014, whereas the share of kerosene was reduced to less than 2%.

Figure 4: Breakdown of final energy consumption by sector in Indonesia, 2010 and 2014



Source: IRENA analysis and MEMR, 2015

Figure 5: Breakdown of residential final energy consumption by carrier in Indonesia, 2000, 2010 and 2014



Source: MEMR, 2015

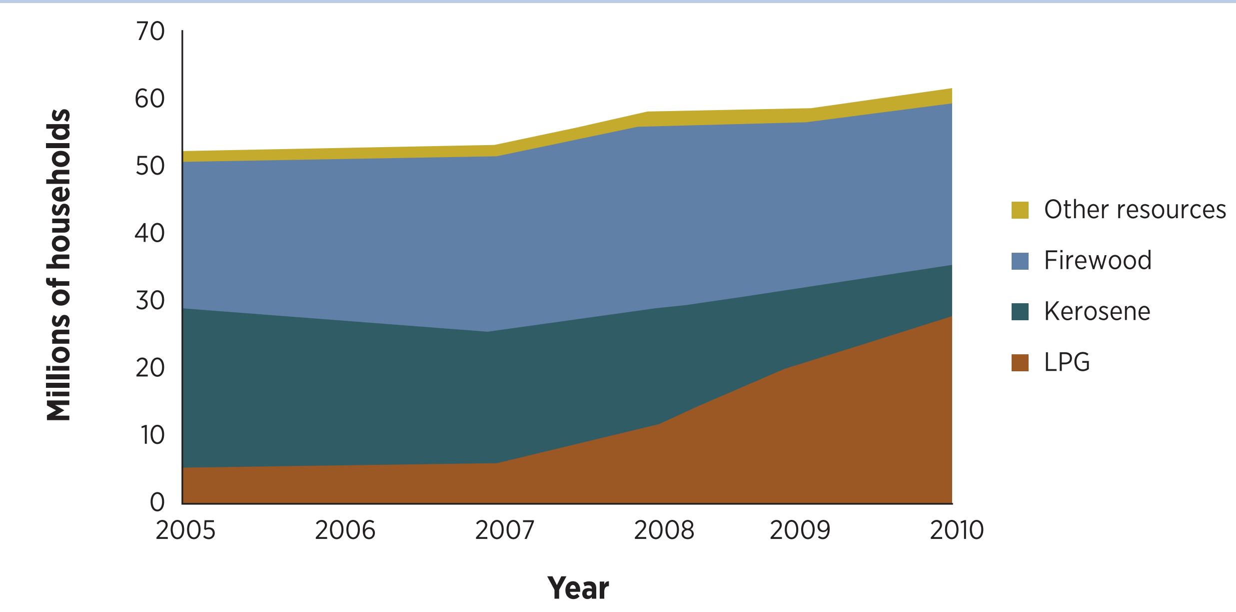
In contrast, the share of bioenergy use (almost all residential) in building energy demand in Indonesia remains high, at over 70%, while in absolute terms its use has increased in recent years (see figure 6). In 2013, an estimated 24.5 million households (nearly 40% of all households) depended primarily on traditional uses of bioenergy for cooking (World Bank, 2013). While the number of households relying on fuelwood – the main form of bioenergy used for cooking – was overtaken by those relying on LPG (see figure 6), fuelwood remains the dominant source for household cooking in terms of final energy consumption. There are great differences, however, in the use of fuelwood across provinces. In Jakarta less than 1% of households depend on fuelwood for cooking, whereas in the 13 provinces with the highest poverty rates (mainly in West Nusa Tenggara, Papua and Sulawesi), nearly two-thirds of households rely primarily on fuelwood as their cooking fuel.

The Indonesian Clean Stove Initiative, a collaboration between the Indonesian government and the World Bank which was initiated in 2012, is the key programme aimed at expanding the use of clean biomass cook stoves in the country. These cook stoves, of which various types exist, have a higher efficiency and reduce indoor air pollution. The initiative provides a roadmap for a complete phase-out of traditional uses of bioenergy for cooking by 2030. To reach this target, the initiative estimates that 10 million households would need to use clean biomass cook stoves by 2020, and 18 million (about 20% of all households) by 2030. Another form of cooking based on modern renewable energy is via the efficient use of biogas. The Indonesia Domestic Biogas Programme (and various related programmes) spurred the installation of some 12–500 units by 2012. Today, some 15 000 biogas digesters are reported to have been installed, out of a long-term target of 1 million systems (MEMR, 2016b).

Electricity is the fastest-growing carrier of energy use in buildings, as increasing electrification rates led to a near tripling in residential electricity consumption from 2000 to 2014. Urbanisation was a key factor. In 2000, 42% of Indonesia's population lived in urban areas. By 2014, this had increased to 53% (World Bank, 2016). In the commercial segment, electricity consumption grew at the same rate and now represents nearly 80% of total energy use, up from 40% in 2000. Air conditioning is estimated to account for more than half of commercial electricity consumption (S-GE, 2013). Sales of air conditioning units in all sectors are estimated to grow by more than 10% per year between 2013 and 2018 (BusinessWire, 2014).

Water heating still accounts for a small share of energy use in Indonesia, especially in rural areas. Energy demand

Figure 6: National trend in household cooking fuel use in Indonesia, 2005-2010



Source: World Bank, 2013

for this application is expected to increase, however, due to economic development and urbanisation. Petroleum products and electricity are currently mainly used for water heating. Solar water heaters have not been adopted on a large scale in Indonesia. The country does not include their contribution in its national energy statistics, nor are they included in international statistics (AEE INTEC, 2015).

Industry

Industry has the largest share of energy consumption in Indonesia at 2.7 EJ in 2014 (excluding non-energy use), or 36% of TFEC. This represents an increase of 5% per year since 2010. Statistics produced by MEMR and by the International Energy Agency (IEA) on industrial energy consumption seem to differ greatly, with the latter's estimate being nearly 1 EJ (or 37%) lower than that of MEMR (IEA, 2015a; MEMR, 2015). The difference is explained almost entirely through the estimated use of coal, which, according to the IEA, has decreased significantly since 2010. According to government statistics (which are used for this report) coal remains the primary fuel for industrial energy consumption, and its use and share in the industrial fuel mix has increased rapidly in recent years (see figure 7).

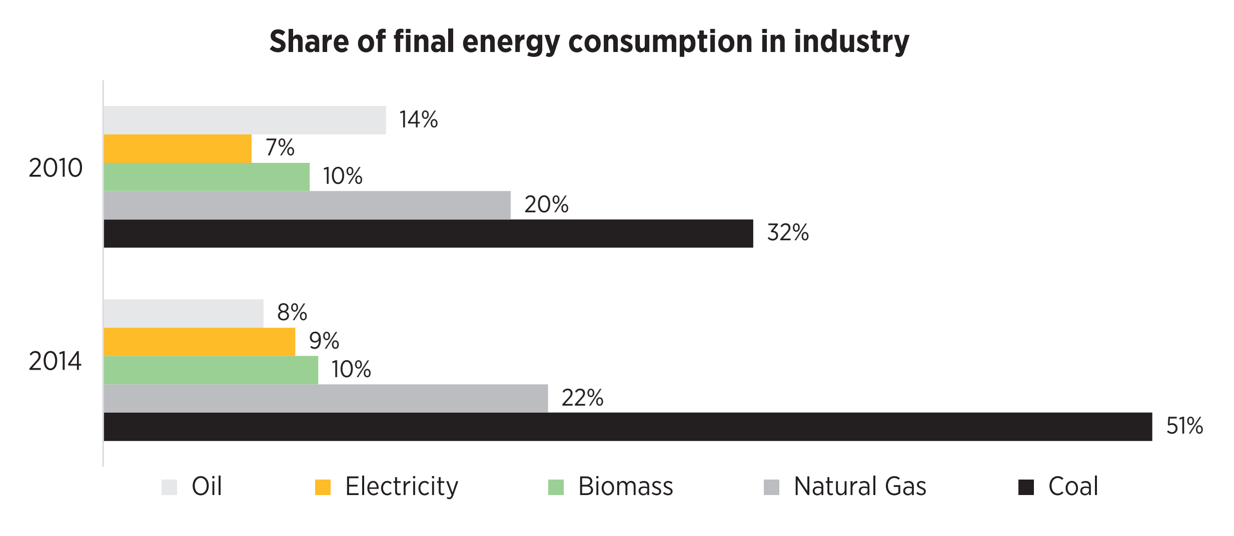
A bottom-up analysis of energy use in selected key industrial sectors in Indonesia reveals that aluminium, cement, ceramics, brick and paper producers are large users of energy in the country (see table 1). As Indonesian manufacturers have yet to adopt geothermal and solar thermal applications, renewable energy use in industry includes only bioenergy, which accounted for 22% of industrial energy use in 2014. The processing of palm oil, sugar and wood is fuelled in part by residues, while small-scale kilns for brick production, for example, often rely on fuelwood and rice husk (Sopingi and Soemarno, 2015).

Transport

Of the main end-use sectors, the growth in transport energy consumption has been the fastest in recent years. In 2010 transport energy demand stood at 1.5 EJ, or 26% of TFEC. By 2014 this had increased to 2 EJ, with transport's share in TFEC expanding to 28%. In absolute terms the growth was 30%.

The growth in motorcycles and motor scooters has been especially rapid in Indonesia, with the installed stock almost doubling between 2008 and 2015 (see figure 8). Currently, there are about 400 two-wheelers in Indonesia per 1000 inhabitants, with about 6.7 million units sold in 2015 alone. Domestic production of motorcycles and scooters in 2015 was about 5.7 million units, representing about 85% of domestic sales (ASEAN Automotive Federation, 2016). Compared to

Figure 7: Breakdown of industrial energy use by carrier in Indonesia



Source: IRENA analysis and MEMR, 2015

Table 1: Analysis of energy use in selected industries in Indonesia, 2014

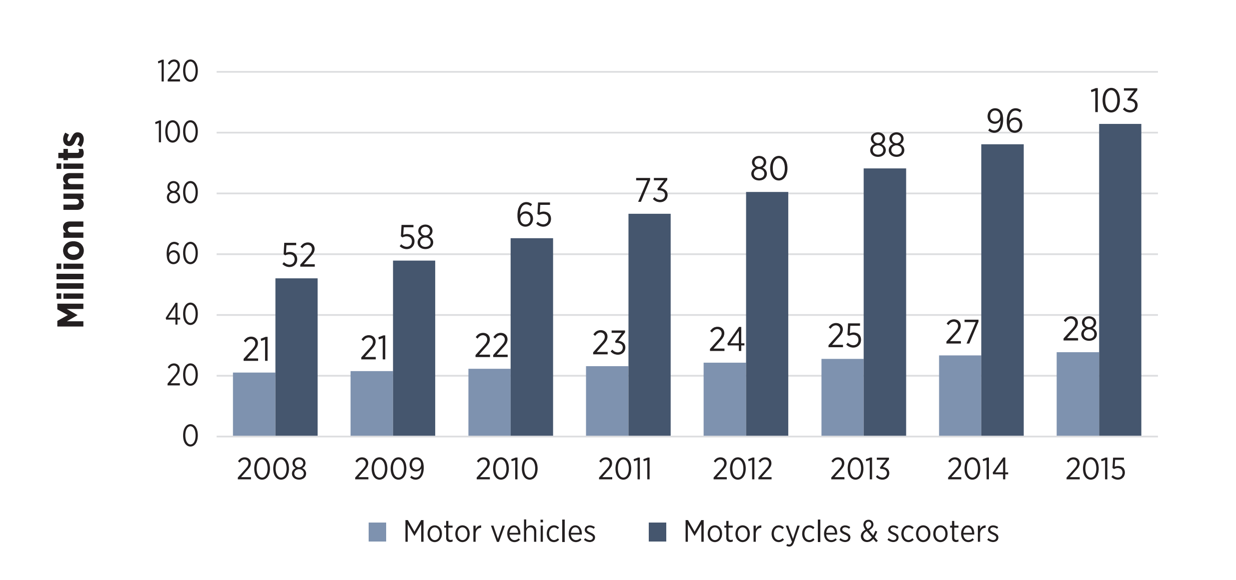
	Pro-duction	Electricity use	Fuel use	Electricity use	Fuel use	Main fuel type	Process temperature level
Unit	**Mt/yr**	**kWh/t**	**GJ/t**	**PJ/year**	**PJ/year**		**Degrees celcius (°C)**
Cement	**60.0**	**120.0**	**3.3**	**20.7**	**201.0**	**Coal**	High (>1000 °C)
Steel (EAF route)	**4.4**	**650.0**		**10.4**	**0.0**		High (>1000 °C)
Ammonia	**6.1**		**15.0**		**91.1**	**Natural Gas**	High (>400 °C)
Aluminium	**0.3**	**16 000.0**	**1 615.3**	**14.4**	**403.8**	**Coal**	High (>1000 °C)
Glass	**3.8**		**16.6**		**62.3**	**Coal**	High (>1000 °C)
Wood processing	**19.0**			**5.3**	**40.2**	**Coal / Biomass**	Medium (150-300 °C)
Plywood	2.3	80.0	8.1	0.7	18.5		
Veneer	0.7	40.0	4.1	0.1	2.9		
Wood chips	9.4		0.1	0.0	1.3		
Pulp	5.6	191.1	2.3	3.9	12.8		
Sawn wood	0.9	213.3	5.3	0.7	4.8		
Paper mill	**14.2**	750.0	8.8	**38.3**	**124.1**	**Coal**	Medium (150-300 °C)
Newsprint	0.7				5.8		
Printing+Writing Paper	4.9				42.5		
Recovered Paper	3.9				34.4		
Other Paper+Paperboard	4.7				41.3		
Natural rubber	**3.2**		**21.0**		**67.2**	**Natural Gas**	Low (150 °C)
Food					**40.3**	**Oil**	Medium (150-300 °C)
Textile					**69.8**	**Oil**	Medium (150-300 °C)
Cotton spinning	3.4		9.6		32.6		
Other					37.2		
Other gross ceramics	**9.4**		**16.6**		**155.4**	**Coal**	High (>1000 °C)
Bricks	**17.4**		**6.1**		**105.2**	**Coal / Biomass**	High (>1000 °C)
Total of selected industries				89.1	**1 360.2**		
Total industrial energy use				247.2	**2 182.0**		

Source: IRENA analysis

other Southeast Asian countries, Indonesia's sales of two-wheelers are particularly high. Sales in 2015 of motorcycles and scooters per 1 000 inhabitants totalled around 26 in Indonesia, compared with 13 in Malaysia and 9 in the Philippines. Clearly, Indonesia is catching up with countries like Malaysia and Thailand which have even higher rates of two-wheeler penetration (KPMG, 2014).

Sales of passenger and commercial vehicles were just over 1 million per year on average between 2011 and 2015. While annual sales have grown about 3% during the same period, Indonesia's sales levels are still low compared to other countries in the region. In Thailand, for example, about 800 000 motor vehicles were sold in 2015. This is 20% lower than in Indonesia, but in relative terms it is much higher given that Thailand's population

Figure 8: Stocks of motor vehicles and motorcycles and scooters in Indonesia, 2008-2015



Source: IRENA analysis; ADB, 2012; ASEAN Automotive Federation, 2016

is only about one-fourth of Indonesia's population. Overall, Indonesia's four-wheeler penetration rate in 2015 remains modest at about 11%, illustrating the potential for a further increase to be expected due to continued economic development.

About half of all transport energy use in Indonesia in 2014 was in the form of gasoline used by road vehicles; another 40% was consumed in the form of diesel in road vehicles. While biodiesel use increased over the last couple of years (see next section), the total share of biofuels in transport TFEC remained modest, at about 2%. Electric mobility is still limited in Indonesia. In 2014, electricity used in transport counted for 0.6 PJ, or less than 0.03% of total energy consumption in transport. Electric vehicles, including electric two- and three-wheelers, are not encountered on a large scale yet in Indonesia due to a lack of government support and regulations. Recently, however, some electric vehicle companies have established a presence in the country, with a hope that the market will take off in the years to come (Manaturi and Tabita Diela, 2015; Octama, 2015). In Jakarta, the construction of a rail-based rapid mass transit system is also under way. The first phase of the project, which is 15.7 kilometres in length and has the capacity for up to 173 000 passengers per day, is expected to be completed by 2019 (Amindoni, 2016).

Energy production

Fossil fuels

Indonesia is a major fossil fuel-producing country. In 2014, Indonesia was the largest exporter of coal and the fourth-largest coal producer worldwide (IEA, n.d.). Coal reserves were estimated at 32 270 million tonnes (Mt) in the beginning of 2014, more than 80% of which are found on East Kalimantan and South Sumatra (MEMR, 2015). The estimated coal reserves would last for another 70 years at current production levels. When total coal resources (hypothetic, inferred, indicated and measured) are considered, this would be 272 years. Coal production stood at 458 Mt in 2014, up from 275 Mt in 2010 and 77 Mt in 2000. Exports accounted for 83% of production, with China, India, Japan and the Republic of Korea accounting for more than half. Most of the coal deposits in Indonesia are medium- and low-calorific varieties of sub-bituminous coal, with low ash and sulphur content, suitable in particular for power generation. Metallurgical coal, used in iron and steel making, is found less in Indonesia (GBG Indonesia, 2014).

Natural gas reserves (proven and potential) in Indonesia amount to 149 trillion standard cubic feet of gas (tscf), with production (associated and non-associated) steady around 3 tscf per year over the past 15 years. About 1 tscf of domestic production in 2014 was used in industry and power; another 1 tscf was consumed by liquefied natural gas (LNG) plants, and 0.3 tscf was exported through gas pipes. Although Indonesia remains Southeast Asia's largest exporter of gas, Indonesia's share of the global LNG market has declined (IEA, n.d.). Its global market share was 20% in the early 1990s but had fallen to less than 10% by the end of 2013 (EIA, 2014).

Oil reserves (proven and potential) in Indonesia amounted to 7.4 billion barrels in January 2014. Crude oil production has been decreasing in recent years – from 517 million barrels in 2010 to 288 million barrels in 2014 – due to the reliance on mature oil fields and to a lack of investment in new oil exploration. Imports therefore have increased: between 2000 and 2014, crude oil imports increased from 79 million barrels to 122 million barrels, while refined product imports increased from 91 million barrels to 209 million barrels.

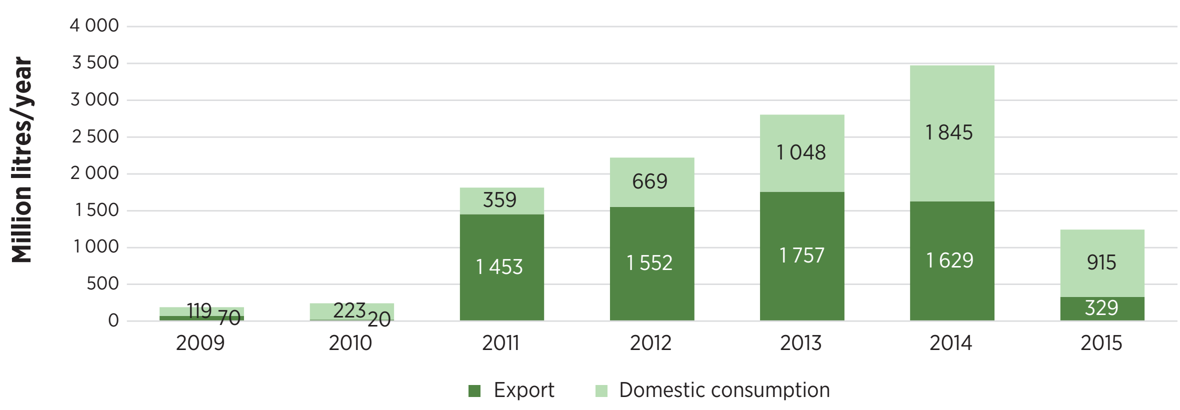
Biofuels

Indonesia was the world's fourth largest producer of biodiesel in 2014, behind the United States, Brazil and Germany (REN21, 2015). The production of biodiesel in Indonesia increased rapidly in the years up to 2014. In 2009, production was estimated at 190 million litres; by 2014 this had increased to 3 961 million litres (MEMR, 2016b). The number of bio-refineries increased from 7 to 26 in the same time frame (USDA, 2015).

Exports accounted for just over half of biodiesel production in 2014 (see figure 9). The share of exports in total production declined greatly in recent years due to the increase in domestic biodiesel blending. Historically, the European Union (EU) was a key market for Indonesian biodiesel, representing 85% of total exports in 2012. Following anti-dumping duties of nearly 19% (on import value) imposed by the EU in 2013, this was reduced to virtually zero by 2014 (EC, 2013). Instead, China evolved as the primary market for Indonesian biodiesel exports at about 55% of total exports in 2014, boosted by China's elimination of biodiesel import taxes. Malaysia was the second largest market, at about 520 million litres (or just over 30% of total exports) in 2014 (USDA, 2015).

However, 2015 marked several structural changes in the Indonesian biodiesel sector. First, the domestic blending mandate was again increased, from B10 to B15. Second, amid sharply falling oil prices in 2014 many Indonesian biodiesel producers faced heavy financial losses, as the Indonesian biodiesel reference price was based on a gasoil benchmark price (Mean of Platts Singapore). This led to a new pricing formula for biodiesel in Indonesia, based on the market price of crude palm oil and allowing for a 3% margin over the biodiesel production cost. Finally, to support local oil companies in adopting the new B15 blending mandate, a new agency (the Indonesian Palm Oil Estate Fund) was introduced to collect funds from palm oil producers through an export levy of USD 3 per tonne of crude palm oil. Nevertheless, due to administrative issues in the establishment of

Figure 9: Indonesian export and domestic consumption of biodiesel, 2009-2015



Source: MEMR, 2016b

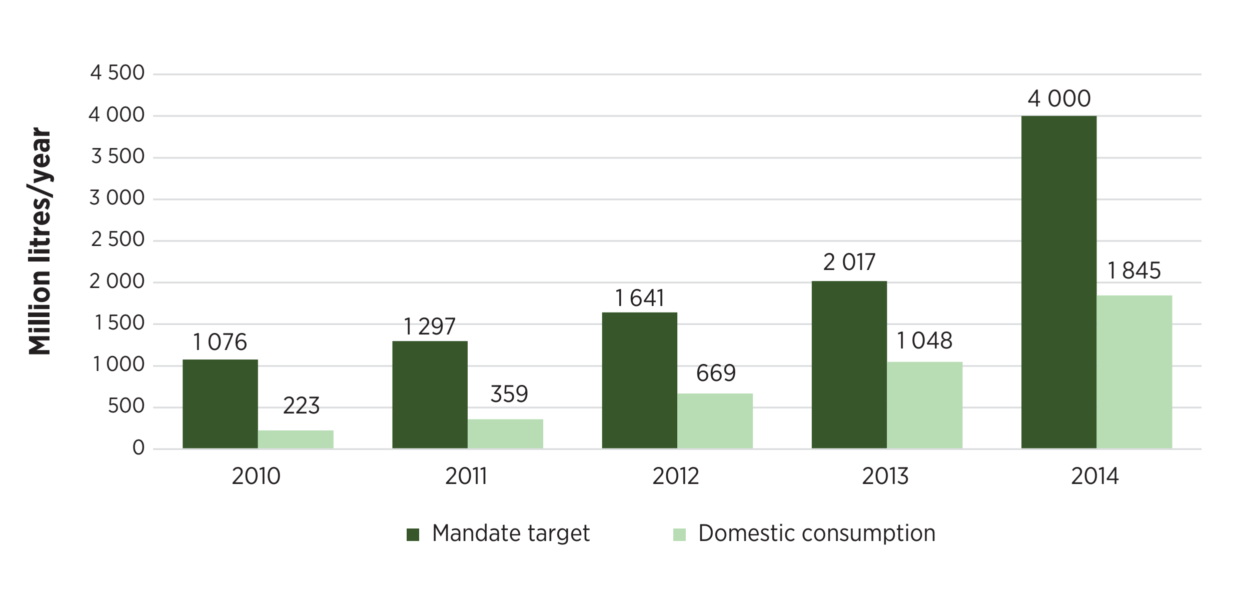
this new agency and in the collecting and managing of funds for subsidy, biodiesel production in Indonesia dropped sharply. In 2015 just over 1.6 billion litres of biodiesel were produced, making Indonesia the eleventh largest producer of biofuels globally that year (down from its position as fourth the year before) (REN21, 2016). Lower oil prices globally meant that exports decreased significantly, while the domestic blending mandate was not fulfilled.

By the first quarter of 2016, it seemed that some of the major subsidy issues had been resolved, and biodiesel production increased again. The government implemented B20 (and B30 for the power sector), and compensation was provided by the Indonesian Palm Oil Estate Fund for subsidised biodiesel (Public Service Obligation – PSO), which is blended for use in transport. The target for subsidised biodiesel was set at 3.2 billion litres for the full year 2016, a sharp increase from 2015. In the first half of 2016, 1.3 billion litres of subsidised biodiesel were blended (KOMPAS, 2016). For the non-subsidised biodiesel (non-PSO, for commerce, industry and power generation), a target of 1.3 billion litres was set for 2016. In the first half of 2016, however, only 50 million litres were blended. This implies that the overall target for blended biodiesel (of 4.5 billion litres) will likely not be met in 2016, which also has been the case in previous years (see figure 10).

Nearly all biodiesel used in Indonesia is produced from palm oil. The total area of palm oil plantations in Indonesia is estimated at approximately 11 million hectares (Mha) today, a rapid increase from just 4 Mha in 2000 (Indonesia Investments, 2016a). Crude palm oil used for domestic biodiesel production accounted for only 1% of the crop's total production in Indonesia in 2008, but by 2014 this had increased to more than 10%. Land clearing for palm oil production is associated with adverse environmental outcomes, such as carbon dioxide emissions as a result of forest fires[8]. In May 2011, the government imposed a moratorium on new palm oil concessions, which was reported to be extended by another five years in July 2016 (Indonesia Investments, 2016b).

Even though Indonesia also has blending mandates for ethanol (2% for transport PSO, and 5% for transport non-PSO and for industry), subsidies have been implemented only for biodiesel. The Indonesian ethanol subsidy programme was ended in 2010 due to pricing schemes that provided insufficient incentives to

Figure 10: Indonesian mandatory biodiesel blending targets and actual domestic consumption, 2010-2014



Source: MEMR, 2016b; USDA, 2015

8 For more on the topic see *e.g.* Wicke *et al.* (2008), Casson *et al.* (2014), Mukherjee and Sovacool (2014), FAO 2014, WRI (2015), and Koplitz *et al.* (2016).

producers. Although some ethanol fuel is produced in Indonesia, it is at a small scale and is mainly exported (USDA, 2015).

Power generation

Total on-grid power generation in Indonesia was 229 TWh in 2014 (MEMR, 2015). About 77% of this was generated by assets belonging to the national utility PLN, with the remainder coming from private power utilities (PPUs) and independent power producers (IPPs). The monopoly position of PLN in power generation has been reduced since 2000, when PLN accounted for 92% of total on-grid power generated in Indonesia. In recent years, however, PLN has expanded generation at a similar pace as PPUs and IPPs, explaining the minimal change of its share in total generation since 2010.

Coal represented a majority of Indonesia's on-grid power generation in 2014 at about 53%, or 120 TWh (see figure 11). This share has increased rapidly; in 2010 the share of coal in power generation was just 40%. Natural gas accounts for another 25% of power generation, with modest changes in its use since 2010. Petroleum products have a share of 10% in power generation. While the share of petroleum products has been stable in recent years, in the longer term it has been shrinking (down from 14% in 2000). This includes rental contracts with the private sector for about 4 GW of diesel generators (mainly in eastern parts of Indonesia), the use of which is planned to be reduced further (PLN, 2016).

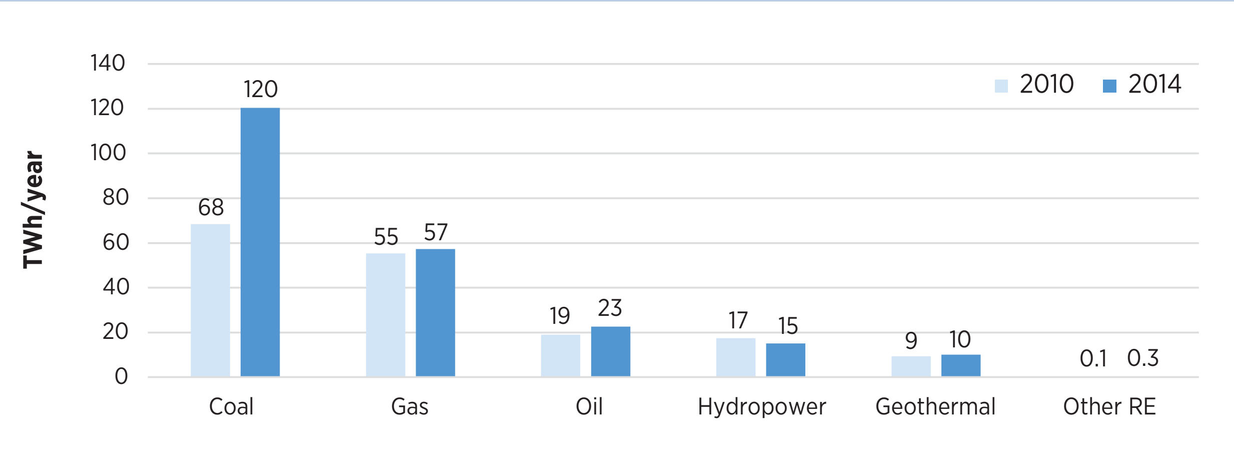
Renewable energy accounted for 11% of Indonesia's total on-grid power generation in 2014, down from 16% in 2010 due to the fact that additional electricity demand was met largely by coal-fired power. Hydropower and geothermal generated 15 TWh and 10 TWh, respectively, of electricity that was fed into the grid in 2014. Other renewables played a small role in on-grid power generation.

On-grid power generation capacity stood at 53.1 GW at the end of 2014. Since 2010, nearly 20 GW of generation capacity has been added to the grid, most of which (13 GW) was new coal power capacity. Geographically, more than 70% of on-grid power generation capacity is on Java-Bali, with a total of 37.5 GW of on-grid generation capacity found there (see figure 12). The share of coal-fired power capacity, at about 55%, on Java-Bali is higher than in other regions. Renewable power has a higher share in Sulawesi & Nusa Tenggara (39%) and Sumatra (17%), due mainly to the utilisation of hydropower resources. Oil-fired power generation plays a larger role on the islands of Kalimantan and in Maluku & Papua, where the use of smaller-scale diesel generators is still widespread.

Hydropower

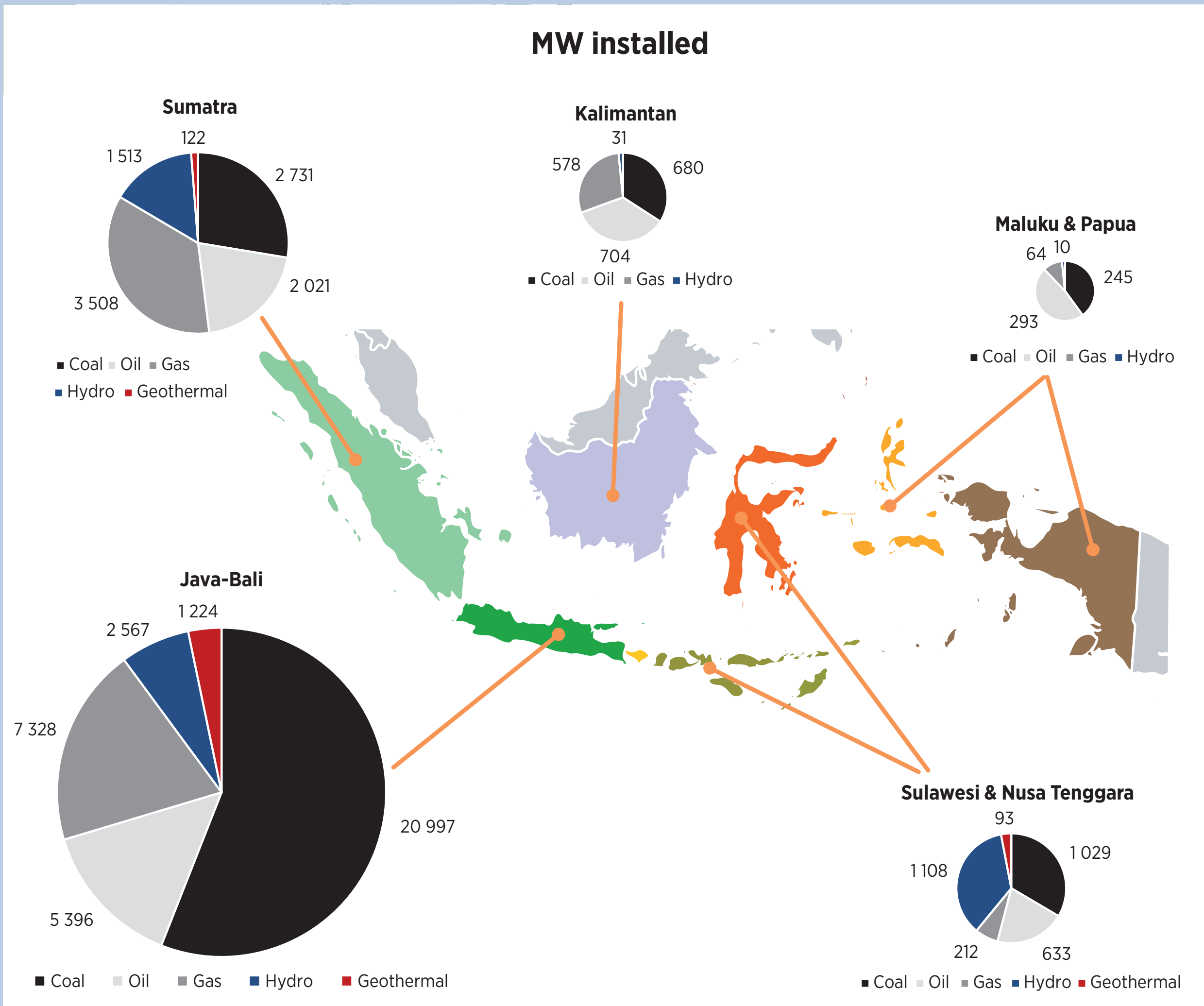
On-grid hydropower capacity stood at 5.2 GW by the end of 2014, a substantial increase from 3.7 GW in 2010. Almost all of the capacity was large-scale hydropower (larger than 50 MW by IRENA definition) and was based on Java-Bali, Sumatra and Sulawesi & Nusa Teggara. The

Figure 11: On-grid power generation in Indonesia, 2010 and 2014



Source: IRENA analysis and MEMR, 2015

Figure 12: On-grid power generation capacity in Indonesia, 2014



Source: IRENA analysis

largest hydro plant in Indonesia has 1 GW of capacity, was constructed between 1984 and 1988, and is located at the Cirata Dam in West Java (Indonesia Hydro Consult, 2015). Small-scale installations increased from just 14 MW in 2010 to 170 MW by the end of 2014, on the back of specific feed-in tariffs for hydropower plants up to 10 MW (MEMR, 2015). The feed-in tariff regulation for hydropower plants up to 10 MW was updated in July 2015, with a new feed-in tariff that exceeds PLN's average cost of power production.

Geothermal

The installed capacity of geothermal power has grown modestly in recent years, from 1.2 GW in 2010 to 1.4 GW by the end of 2014. This was despite ambitions to grow geothermal capacity more quickly: in 2010 the target for 2014 was set at 4 000 MW from 44 additional plants (Allard, 2010). While a feed-in tariff was introduced in 2012 for geothermal power, progress has been slow due to institutional, regulatory and tariff constraints (ADB and World Bank, 2015). Java accounts for 85% of installed geothermal capacity, at 1.2 GW. Starting in January 2016, more than 1 GW of geothermal power projects over eight working areas were scheduled to be tendered during 2016 and 2017 (Sundaryani, 2016a).

Bioenergy

Of a total of 1.6 GW of bioenergy power capacity (mainly from residues and waste in the palm and paper industries), 92 MW was grid-connected in 2014. The

Box 1: Indonesia's long history in considering nuclear energy

Indonesia has a long history in assessing the potential of nuclear energy in meeting the country's rapidly growing demand for energy. The National Nuclear Energy Agency of Indonesia (BATAN) was founded more than five decades ago in 1958, and in the decades since it has led various research and development (R&D) initiatives, including the construction of small-scale atomic reactors, fabrication and fuel research, reactor safety testing and radioactive waste management (BATAN, 2016). In 1996, the first comprehensive feasibility study was conducted for a large-scale nuclear power plant in Indonesia (in central Java). While plans for an initial plant were deferred the year after, renewed interest in the potential of nuclear emerged in the early 2000s, with a power generation strategy showing the option for 2 GW to be developed by 2016.

In 2006 it was decided that an IPP could be awarded a project for building and operating nuclear plants, with sites on the central-north coast of Java being considered. Plans for tenders in 2008 were then put on hold, and in mid-2010 three sites were being considered in central and west Java and in Bangka Island (off the southern coast of Sumatra). For the latter location, BATAN undertook a feasibility study during 2011-2013 and identified as much as 10 GW of potential for meeting electricity demand in Sumatra, Java and Bali. However, after a change in provincial government, the identified sites on Bangka Island were no longer considered. Subsequently, BATAN shifted its focus to West Kalimantan, assessing the potential for small reactor units and stating that an initial 30 MW experimental nuclear power reactor could potentially be in operation by 2019. In April 2015 the Russian company Rusatom, responsible for promoting Russian nuclear technologies overseas, announced that a consortium of Russian and Indonesian companies won a contract for the preliminary design of a 10 MW high-temperature reactor in Indonesia (World Nuclear Association, 2015).

At present, the Draft General Plan of Electricity (RUKN) 2015-2034 does not include any target for nuclear energy until 2025 (MEMR, 2016a). The 2030 Reference Case for Indonesia, as presented in this report, also excludes nuclear energy as part of the energy mix, given recent statements by the government that nuclear is not expected to play a part in the country's energy mix in 2025 and 2050 (Prakoso, 2015).Indonesia has a long history in assessing the potential of nuclear energy in meeting the country's rapidly growing demand for energy. The National Nuclear Energy Agency of Indonesia (BATAN) was founded more than five decades ago in 1958, and in the decades since it has led various research and development (R&D) initiatives, including the construction of small-scale atomic reactors, fabrication and fuel research, reactor safety testing and radioactive waste management (BATAN, 2016). In 1996, the first comprehensive feasibility study was conducted for a large-scale nuclear power plant in Indonesia (in central Java). While plans for an initial plant were deferred the year after, renewed interest in the potential of nuclear emerged in the early 2000s, with a power generation strategy showing the option for 2 GW to be developed by 2016.

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government is actively stimulating more power from bioenergy to be connected to the grid, which was less than 20 MW in 2010. Specific feed-in tariffs for biomass, biogas and municipal solid waste were put in place to support this ambition (Kusdiana, 2014).

Solar PV

Estimates of total solar PV capacity in Indonesia vary, from 42 MW by the end of 2012 (MEMR, 2014b) to 80 MW installed in 2010 and 2011 alone (IEA, 2015b). For the on-grid component, the installed capacity is estimated at around 10 MW. The largest power plants are located in Bali (2 MW), Kupang (5 MW) and Gorontalo (2 MW). By mid-2016 there was over 700 MW in memorandums of understanding as well as commitments by PLN to develop utility-scale solar PV systems in Indonesia. Some involve private sector developers such as Savills, Quantum Energy Indonesia and Akuo Energy, as well as Indonesia's state-owned Pertamina (Kurniawan, 2016). The announcement in July 2016 of a new feed-in tariff to support 250 MW of solar PV installation is likely to further support the market in the coming years (Susanto, 2016).

Wind

The installed wind power capacity is estimated at 9.4 MW in early 2016 (WHyPGen, 2016). In the first nine months of 2016, three PPAs were signed for the development of wind farms in Indonesia: 50 MW in Samas (Java), 60 MW in Jeneponto (Sulawesi) and 70 MW in Sidrap (Sulawesi), which recently achieved financial close (Ver-Bruggen, 2016). At the same time more than 500 MW in projects was in negotiation for PPA or was in the feasibility study/data validation stages (WHyPGen, 2016).

Off-grid power

Different estimates exist for the power capacity that is not tied to the main grids operated by PLN. This off-grid capacity consists of on-site industrial power capacity, mini-grids and stand-alone generation in rural areas (based on diesel generators, micro hydropower, solar PV, biogas plants and micro-wind), and solar home systems.

IRENA estimates the on-site industrial power capacity at about 4.4 GW in 2014. This includes 1.6 GW of bioenergy power capacity that was located in the paper (955 MW) and palm (450 MW) industries. Geographically, more than 80% was located on Sumatra (Kusdiana, 2014). The remaining on-site industrial capacity includes waste heat, coal, oil and gas. Furthermore, it was estimated that about 30 000 diesel gen-sets are in operation in rural areas of Indonesia, in addition to the 4 600 diesel gen-sets that PLN operates (Blocks, 2013). This form of off-grid rural power generation is estimated to represent about 900 MW. This is somewhat below an estimate for 2007 in which decentralised diesel power plant capacity amounted to 987 MW that year (Schmidt *et al.*, 2013).

The Energising Development (EnDev) partnership states that it has supported 286 micro hydropower and 222 solar PV mini-grid installations in Indonesia to date, at a reported size ranging from 5 kW to 400 kW (EnDev, 2015). Most of these were funded by the government, and many have been turned over to local governments or local communities. IRENA estimates that this accounts for about 30 MW of micro hydropower and 10 MW of solar PV. Finally, an estimated 264 000 solar home systems were installed in Indonesia by the end of 2010 (IRENA, 2015a). As the common solar home system in Indonesia at the time came with a 50 Watt module (Sudradjat, 2011), this would imply about 13 MW of installed off-grid solar PV capacity by the end of 2010. Starting in 2012 MEMR has funded the installation of about 500 off-grid centralised solar PV systems in remote villages. These off-grid systems range in size from 5 kW to 150 kW. Aggregate data on biogas plants in rural areas and small-scale wind systems are not available.

Clearly, renewables already play an important role in the off-grid power segment in Indonesia, and more potential (in particular for solar PV) has been identified to electrify remote villages that are unlikely to be connected to larger grids anytime soon.

2.2 Drivers for renewable energy

Indonesia has set ambitious targets for renewable energy, which should account for a 23% share of modern renewable energy in TPES by 2025, compared to less than 6% in 2014. Indonesia, like 163 other countries that had national-level renewable energy targets in 2015, is recognising the many benefits that accelerating renewable energy deployment can have for the country (IRENA, 2015b). A brief overview of these is provided below.

Health and environmental impacts

In 2012 an estimated 4.3 million people worldwide died prematurely from illness related to household air pollution, and another 3.7 million premature deaths were caused by ambient (outdoor) air pollution (WHO, 2014). In Indonesia both outdoor and indoor pollution present major problems to human health, and fossil fuel combustion is a significant contributor. It is estimated that existing coal plants in Indonesia were responsible for 6,500 premature deaths, with each additional 1 GW coal power plant expected to cost around 600 more lives per year (Boren, 2015). Indeed, the combustion of coal for power generation and industrial processes accounts for three-quarters of energy-related sulphur dioxide (SO_2) emissions in Southeast Asia today, and Indonesia accounts for half of the emissions from coal-fired power generation in the region (IEA, 2016a).

The rapid increase in the use of motorised vehicles also is contributing to poor levels of air quality, particularly in Indonesia's major cities. In Jakarta the average cost of air pollution illnesses in 2010 alone was estimated at USD 535 million, with PM_{10} concentrations that historically have been twice as high as World Health Organization guidelines (ICCT, 2014). The premature deaths per year in Indonesia related to negative health impacts from indoor air pollution due to traditional bioenergy use for cooking are estimated at 165 000, making clear the urgency for a transition to modern cooking technologies (World Bank, 2013).

Fossil fuel combustion in Indonesia also contributed greatly to global warming. Greenhouse gas emissions in Indonesia were estimated at 1800 Mt CO_2-eq in 2005, an increase of 400 Mt CO_2-eq from 2000. Of total greenhouse gas emissions in 2005, land-use change (including related to fossil fuel resource extraction) and peat and forest fires accounted for an estimated 63%, and another 19% was directly related to fossil fuel combustion. Also in 2015, forest fires from land clearing (as discussed in section 2.3) accounted for more than 850 Mt of CO_2 emissions, with daily emissions during the times of fire exceeding total daily emissions across the 28 countries of the EU (Huijnen *et al.*, 2016).

Carbon dioxide emissions from fossil fuel combustion were estimated at 322 Mt CO_2 in 2005, and further increased to 425 Mt CO_2 by 2013 (IEA, 2015c). Nearly 40% of emissions in 2013 were related to power generation, with another one-third caused by transport. Indonesia's Nationally Determined Contribution (NDC) sets an unconditional target for greenhouse gas emissions reductions by 2030 of 29% below business-as-usual, as well as a conditional 41% reduction subject to the provision of international support (UNFCCC, 2016).

At a local level, coal mining in Indonesia is having direct negative impacts on the environment, including contributing to water pollution and desertification. A study by Greenpeace on the effects of coal mining on water quality in South Kalimantan concluded that 45% of the region's rivers are at risk of toxic pollution from coal concessions (Greenpeace, 2014). The rapidly increasing coal mining activities across Kalimantan and the ensuing water pollution is already affecting local agriculture (*e.g.*, leakage of wastewater into rice paddies) and aquaculture operations (Ives, 2015).

The demand for water for cooling coal power plants presents another issue. Despite the abundance of fresh water (2 trillion m^2 of internal renewable water resources, or about 20% of total freshwater in the Asia-Pacific region), 37 million Indonesians lack access to safe water as a result of insufficient infrastructure and distribution networks (Hooley, 2016). Based on 2013 data it was estimated that 5 GW of coal power capacity in Indonesia was planned in red-list areas (defined as areas where baseline water stress exceeds 100%), or about 12% of the total planned coal power capacity in Indonesia at that time.

Macro-economic impacts

The macroeconomic benefits of renewable energy are demonstrated by the positive impact on indicators such as GDP, trade, employment and welfare (IRENA, 2016b). For Indonesia, IRENA estimates that accelerated renewable energy deployment could increase Indonesia's GDP by between 0.3% and 1.3% in 2030, mainly as a result of higher overall levels of investment in the energy sector. The trade balance of Indonesia could improve by an estimated 0.9% to 1.6% in the same year. At the same time, the number of renewable energy-related jobs in Indonesia could increase to 1.3 million by 2030, up from 101 800 in 2015 (IRENA, 2016c). At present, more than 90%

of the renewable energy jobs are in the labour-intensive palm oil-based biodiesel industry, but this would be more diversified if investments in other areas increase. Finally, the impact on overall welfare – a broader indicator that includes not only the economic dimension but also social and environmental factors – is estimated to be between 3.6% and 5.8% in 2030 (IRENA, 2016b).

The use and manufacture of renewable energy technologies also could lead to technology transfer, with additional positive indirect effects on the economy. Already, technology and innovation have been identified as key pillars to the country's economic growth strategy, illustrated by the initiative to establish and develop 100 science and technology parks across the country (INNO SMES, 2015). To support the creation of green jobs in Indonesia, skill development is reported as a focus area due to a large under-educated labour force living in rural areas (causing information lags of green knowledge transfer); to green technologies not being included in technical education curriculums; to underutilised and unclear targeting of vocational training centres; and to a lack of educating the public on green technologies and knowledge (UNIDO and GGGI, 2015).

Energy security and access

Despite the fact that Indonesia is a large producer of fossil fuels, imports of petroleum products into the country have been increasing in recent years, mainly to meet the rapidly growing demand for petroleum and diesel for transport. The government has identified the additional use of domestic natural gas, coal and renewables to reduce dependence on energy imports. The government and PLN are already actively lowering petroleum-based fuel use in power generation, with an aim to lower its share of PLN's generation to below 6.7% in 2016 (Sundaryani, 2016b). Given the detrimental impacts of coal mining and burning on human health and the environment, and to ensure the continuation of revenues from LNG exports, increasing the use of renewable energy presents a clear alternative. Moreover, renewables have been identified as a key technology in increasing electrification, particularly for connecting remote, rural areas of Indonesia.

3 CURRENT POLICY FRAMEWORK

3.1 Background

The energy sector in Indonesia continues to be heavily regulated by the government. While the power sector opened up initially in 1985 by allowing private sector participation in power generation, the Asian financial crisis in the 1990s hit Indonesia hard and many PPAs were abandoned or renegotiated. In the first decade of the 2000s, private sector participation gradually increased again. The first phase of the Fast Track Program (FTP) in 2006 aimed to build 10 GW of power capacity to meet rapidly growing electricity demand, allowing for direct tendering of projects with inclusion of the private sector. The 2009 Electricity Law strengthened the regulatory framework with a greater role for the private sector in power generation, resulting in more focus on the use of IPPs in the second phase of the FTP, which was launched in 2010.

At present, state-owned enterprise PLN is responsible for transmission and distribution of electricity in Indonesia, while electricity prices are set by the government (PWC, 2013). The government plays a large role in other sectors as well. Domestic prices for fuels and electricity are directly set by the government, while state-owned enterprises like Pertamina (oil and natural gas production and exports), PGN (natural gas transportation and distribution) and PGE and GDE (both geothermal energy) continue to be dominant players in their respective industries (ADB, 2015a).

3.2 Renewable energy targets and policies

Indonesia's Nationally Determined Contribution

In its Nationally Determined Contribution (NDC), Indonesia pledges to reduce greenhouse gas emissions unconditionally by 29% by 2030, compared to a business-as-usual scenario with projected emissions of 2 869 Mt CO_2-eq in the same year (UNFCCC, 2016). In addition, the NDC includes a conditional 41% reduction, which is subject to the provision of international support in the form of bilateral co-operation on technology development and transfer, capacity building, payment for performance mechanism, technical co-operation and access to financial resources.

Furthermore, the NDC states Indonesia's strong commitment to implement the planned climate change mitigation and adaptation activities to be led and co-ordinated among various stakeholders including governmental institutions and the newly established Directorate General of Climate Change, under the Ministry of Environment and Forestry. Regulation No. 21/2008 addresses emission regulations in Indonesia, such as the requirement for thermal power plants to install emissions monitoring systems and prepare an emission inventory. While improvements have been made, it is reported that there is no consolidated review of impacts, and monitoring and enforcement of the regulation may be insufficient at present (UNEP, 2016).

Overall renewable energy targets

In October 2014 the revised National Energy Plan was issued as government regulation No. 79/2014, replacing the 2006 National Energy Plan. This plan included the ambition to reach a renewable energy share of 23% in TPES (excluding traditional uses of bioenergy) by 2025 and at least 31% by 2050, targets which also were stated in the country's NDC. Exports of coal and natural gas were stipulated to be reduced gradually due to concerns related to energy security (IEA, 2014). The Indonesian target matches the region-wide ASEAN target for a 23% renewable energy share in TPES by 2025, as announced in October 2015 (ACE, 2015b). Indonesia has an important role to play in enabling the ASEAN region to reach this target, given that the country accounts for nearly 40% of the region's total energy demand.

Power sector targets

The draft National Electricity General Plan (RUKN) 2015-2034, prepared by MEMR, includes specific targets for various renewable energy technologies by 2025. In total, renewable energy capacity installed in 2025 is targeted to be 45 GW, up from 8.7 GW in 2015 (MEMR, 2016a).

Hydropower represents the largest share, with 21 GW installed (of which 3 GW is envisioned to be in the form of small-scale hydropower, defined as having less than 10 MW of capacity per plant), followed by geothermal power (target of 7.1 GW by 2025), solar PV (6.4 GW), bioenergy power (5.5 GW), ocean power (3.1 GW) and wind (1.8 GW).

Power sector regulations

The establishment of MEMR Regulation No. 31 in 2009 provided PLN with a legal basis for buying renewably generated power from IPPs. Regulation No. 4 in 2012 superseded this regulation, setting specific feed-in tariffs for bioenergy power (biomass, municipal solid waste and landfill gas) and hydropower projects up to 10 MW that vary based on the region where the project was installed. Since then, more detailed regulations have been implemented for various renewable energy technologies (see table 2). For larger-scale projects, such as hydropower and more recently wind power, PLN negotiates directly with project developers for a PPA. For most small-scale renewable energy projects (up to 10 MW), feed-in tariffs are the policy mechanism of choice in Indonesia, although auctions for small-scale solar PV projects also were used in the past (Irfany, 2015).

In 2015 the Indonesian Supreme Court issued a decision requiring MEMR to revoke a previous auction regulation for solar PV, based on a case by the Indonesian Solar Module Association. Until then, seven tenders had been conducted for the purchase of solar power (Baker and McKenzie, 2015). As a result of this process, seven solar tenders, totalling 15 MW, were awarded in the provinces of East Nusa Tenggara (five locations), Gorantalo (one location) and South Kalimantan (one location) (Susanto, 2015). The bids were won with tariffs ranging from USD 0.18 per kWh to USD 0.25 per kWh. In July 2016 a new regulation on the purchase of power from solar PV was announced (Susanto, 2016).

In February of 2017 it was announced that the Energy and Mineral Resources Ministry had issued the latest feed-in tariff policy regime for renewable energy. The regulation, Minister Decree No. 12 of 2017, covers all renewable energy types and sets a price based on negotiations between independent power producers and PLN. Importantly it sets a feed-in tariff for projects in a region that range from 85% up to equal cost of that region's PLN production cost. Adjustments are made to the feed-in tariff based on differentiations between the national and regional production cost (Jakarta Post, 2017).

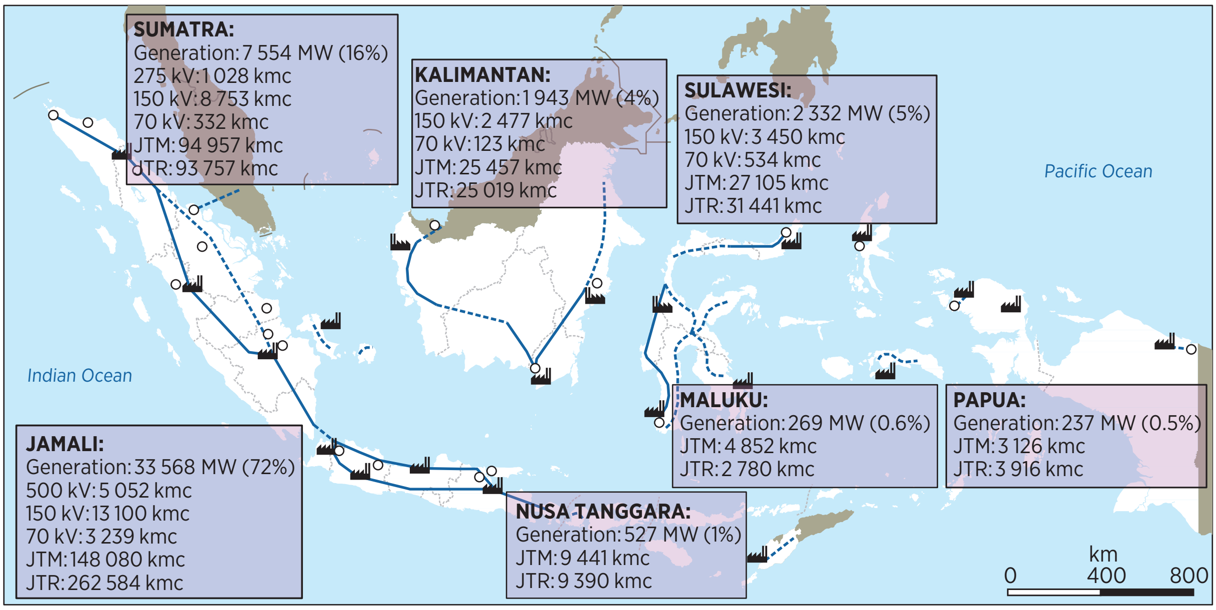
To streamline interconnections of renewable generation, PLN issued in 2014 its guidelines for connecting renewable energy generation plants to PLN's distribution system. These guidelines, applicable to new non-PLN owned renewable energy plants that are less than 10 MW in size, specified two tracks for connection review and analysis. The fast-track review applies to smaller projects (<2 MW in Java-Bali, <200 kW outside Java-Bali) that meet certain eligibility criteria (not exceeding 25% of feeder peak load, compatible line configuration, etc.). For other projects, PLN requires project developers, in addition, to conduct a connection feasibility study, a distribution system impact study and a connection facilities study (PLN, 2014a).

PLN states that power system planning is based on achieving a lowest net present value of electricity supply cost (which is similar to achieving the lowest levelised cost of electricity), while meeting certain reliability criteria such as loss of load probability less than one day per year, with reserve margins of 25-30% in Java-Bali and 40% in the rest of the country. Renewable energy generation capacity additions are treated as "fixed systems" and are permitted to enter the grid with no economic optimisation. For small non-interconnected or isolated systems, PLN does not apply the economic optimisation process, but rather uses a deterministic method with a criteria that the minimum reserve must be greater than the two largest generation units (PLN, 2014b).

Transmission and distribution

PLN takes sole responsibility for transmission and distribution planning in Indonesia. PLN is responsible for expanding transmission capacity and maintains a *de facto* monopoly on distribution expansion through a right-of-first-refusal for projects (ADB, 2015a). Transmission and distribution plans are captured in PLN's annually updated Electricity Supply Business Plan (RUPTL), of which the 2016-2025 edition is the latest version (PLN, 2015). Currently Indonesia has about 40 000 circuit-kilometres of transmission lines across eight interconnected networks and 600 isolated grids (ADB, 2015a). PLN distinguishes three regions for its

Figure 13: Electricity network in Indonesia, 2014



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Note: kmc = kilometre of circuit; JTM = medium-voltage network; JTR = low-voltage network. Factories indicate presence of major power generation plants

Source: IEA, 2015b

operations: Java-Madura-Bali ("JAMALI"), Sumatra and East Indonesia (EY, 2015). Expansion plans for the period up to 2025 would more than double transmission capacity by adding about 67 900 kilometres of transmission across the country, where Sumatra (25 435 kilometres) and JAMALI (18 471 kilometres) account for nearly two-thirds of the total (PLN, 2016).

Included in the plans for transmission expansion is the 500 kilovolt direct current (kVDC) interconnection between Sumatra and Java in the coming years, to allow for additional coal-fired power capacity on Sumatra to meet rapidly growing electricity demand in Java and to better distribute electricity and alleviate frequent blackouts on the two islands (Dahrul, 2014). Plans for other interconnection between Indonesia's islands are not included in current plans. At the beginning of 2016 the first power trading between Indonesia and Malaysia started with the interconnection between Sarawak (Malaysia) and West Kalimantan (FMT, 2016). A project to connect Malacca (Malaysia) and Sumatra is also under way, while a connection between Sabah (Malaysia) and North Kalimantan is in the planning stages. These projects are part of a larger effort to increase interconnections between countries in ASEAN, as part of the ASEAN Power Grid initiative. This initiative aims to expand cross-border interconnections in the ASEAN region from 9 today to more than 30 beyond 2020 (Hermawanto, 2016).

Up to 2025, distribution capacity also is set to nearly double with the addition of 44 000 MVA in transformer capacity, 159 000 kilometres of medium-voltage lines and 133 000 kilometres of low-voltage lines. This is in addition to the 46 800 MVA of capacity that PLN operated in 2014, with 925 300 circuit-kilometres of distribution lines. It should be noted that power system expansions as planned by PLN are often held back by a lack of financing as well as time-consuming approvals for rights of way and substations (ADB, 2015a). A recent regulation allows for the shared use of both transmission and distribution networks. Typically, these transmission and distribution lines are owned and operated by PLN. This power wheeling regulation opens the possibility for power plants to have captive consumers and provide electricity to those consumers by utilising PLN's existing transmission and distribution lines. While the details, such as wheeling fees, have yet to be announced in the upcoming implementing regulations, it provides the overall framework for power wheeling in Indonesia.

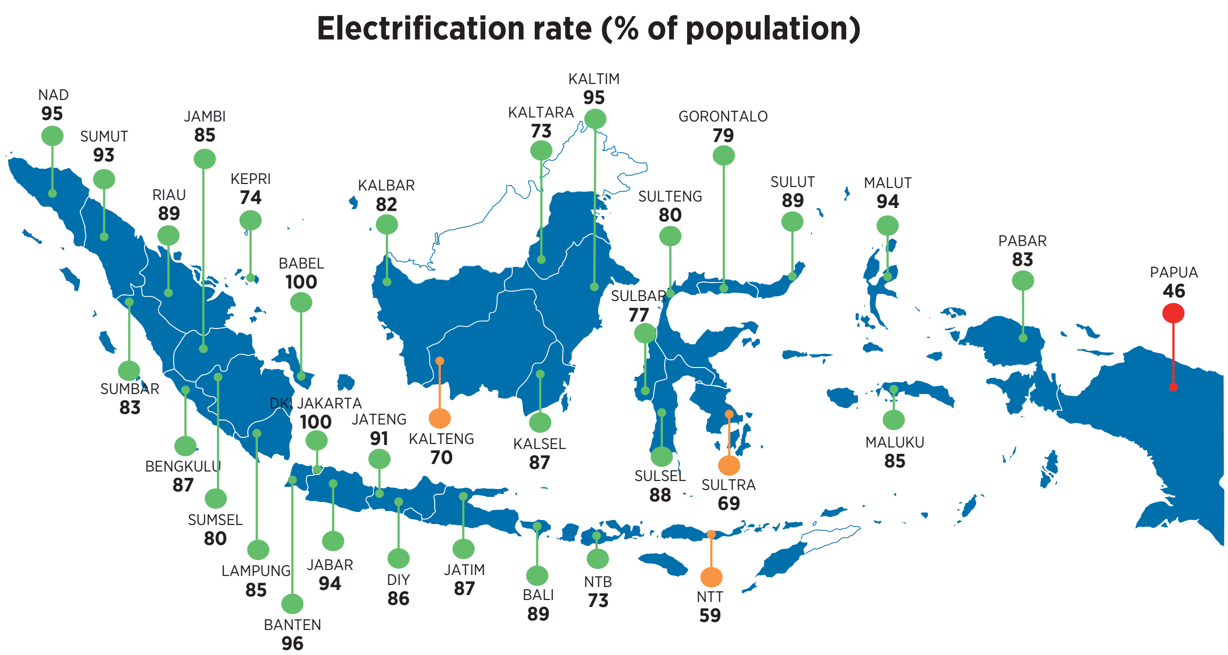
Electrification

By 2015 the overall electrification rate in Indonesia was estimated at 88%, up from just 67% in 2010 (MEMR, 2016a). The target of the Indonesian government is to reach 97% by 2019 and 99.7% by 2026. Great differences exist across the various islands of Indonesia (see figure 14). While more densely populated and economic developed provinces on Java already have electrification rates higher than 90%, provinces mainly in the east of Indonesia, such as East Nusa Tenggara and Papua, are less developed and face electrification rates below 60%. Electrification in these more remote locations will be a combination of providing interconnection to existing grids and developing new mini-grids. For the latter, distributed solar PV has been identified as a key resource, with the potential for electrifying close to 7 000 villages (representing about 1.3 million households) in this way by 2020.

Targets for end-use sectors and energy efficiency

Beyond the power sector, mandates for biofuel blending are a priority area for the Indonesian government in promoting renewables. Biodiesel targets especially have been ambitious, with a mandate for 20% blending in diesel for 2016 and a targeted 30% by 2025. These targets include not only transport, but also diesel use in industry and power generation. For ethanol, blending mandates have not been implemented to date, due to infrastructure shortcomings, feedstock supply gaps and an overall focus on biodiesel (USDA, 2015). Nevertheless, ambitious targets for 20% ethanol blending in industry, power and transport are set for 2025. In addition, the

Figure 14: Electrification rates across Indonesia, 2015



Source: MEMR, 2016a

Table 2: Overview of targets, policies and regulation for renewable energy in Indonesia

	Targets for 2025	Current policy framework and instruments	Regulation
Overall targets			
Renewable energy in TPES (excluding traditional uses of bioenergy)	23%		Government Regulation No. 79/2014
Renewable energy in power generation	25%		Draft RUKN 2015-2034 (plan, no regulation)
Power sector targets			
Large hydropower	18.3 GW	Regulation allows for power purchase through direct selection or direct appointment without the minister's approval as long as the tariff does not exceed the levelised base cost at the power plant's busbar.	MEMR No. 03/2015
Small hydropower	3.0 GW	Different feed-in-tariff for projects up to 250 kW (low voltage) and 10 MW (medium voltage) for 20 years. Rates vary for years 1-8 and 9-20, and between locations (60% premium for Papua, for example). Tariff range is indexed at USD 0.12-0.144/kWh for the first 8 years and USD 0.075-0.09/kWh for years 9-20.	MEMR No. 19/2015
Bioenergy power	5.5 GW	Feed-in tariffs in the range of about USD 0.108-0.272/kWh depending on location, voltage (low/medium) and type of bioenergy (biomass, biogas, municipal solid waste). Acceleration of municipal solid waste power plants are done for seven specific cities and include, as an example, ease of permitting and the use of government funds to pay for the feasibility studies.	MEMR No. 21/2016 (biomass and biogas) and MEMR No. 44/2015 (municipal waste) Presidential Decree No. 18/2016 (municipal solid waste)
Geothermal power	7.1 GW	Direct geothermal within conservation forests only allowed when used for nature tourism activities. For indirect geothermal (power) need permit from Ministry of Forestry if location is in forest areas. Tariff range of USD 0.122-0.296/kWh dependent on year of commercial operation and area in which project is located.	MEMR No. 17/2014 Republic of Indonesia Law No. 21/2014
Solar PV	6.4 GW	Feed-in tariff for 250 MW of capacity, with 150 MW in Java and the remaining 100 MW spread over other locations. Feed-in tariffs range from USD 0.145/kWh in Java to USD 0.25/kWh in Papua for 20 years.	MEMR No. 19/2016
Wind	1.8 GW	Not covered by specific regulation at the moment, although a feed-in tariff is under discussion. Current projects directly negotiated with PLN.	
Ocean power	3.1 GW	Not covered by specific regulation.	
Ethanol blending			
Transportation	20%	2% blending mandate in transportation (PSO), 5% in non-PSO transportation for 2016.	MEMR No. 12/2015
Industry	20%	5% blending mandate for 2016.	MEMR No. 12/2015
Biodiesel blending			
Transportation	30%	20% blending mandate for 2016.	MEMR No. 12/2015
Industry	30%	20% blending mandate for 2016.	MEMR No. 12/2015
Electricity	30%	30% blending mandate for 2016.	MEMR No. 12/2015
Aviation blending	3% (2020)	Alternative biofuel for aircraft, 2% blending mandate for 2018.	MEMR No. 12/2015

Indonesia State Action Plan to Reduce Emissions in the Aviation Sector proposed in 2013 to achieve a 2% blend for aircrafts by 2018, and 3% by 2020 (Gona, 2013).

Energy efficiency represents another important focus area for Indonesia. In 2005, the National Master Plan for Energy Conservation (RIKEN) identified the potential to reduce energy intensity by 1% per year until 2025. An updated draft version of the RIKEN is awaiting approval, which includes targets for industry (17% reduction in final energy consumption from a business-as-usual scenario), transport (-20%) and the commercial and residential sectors (-15%) (IEA, 2016b).

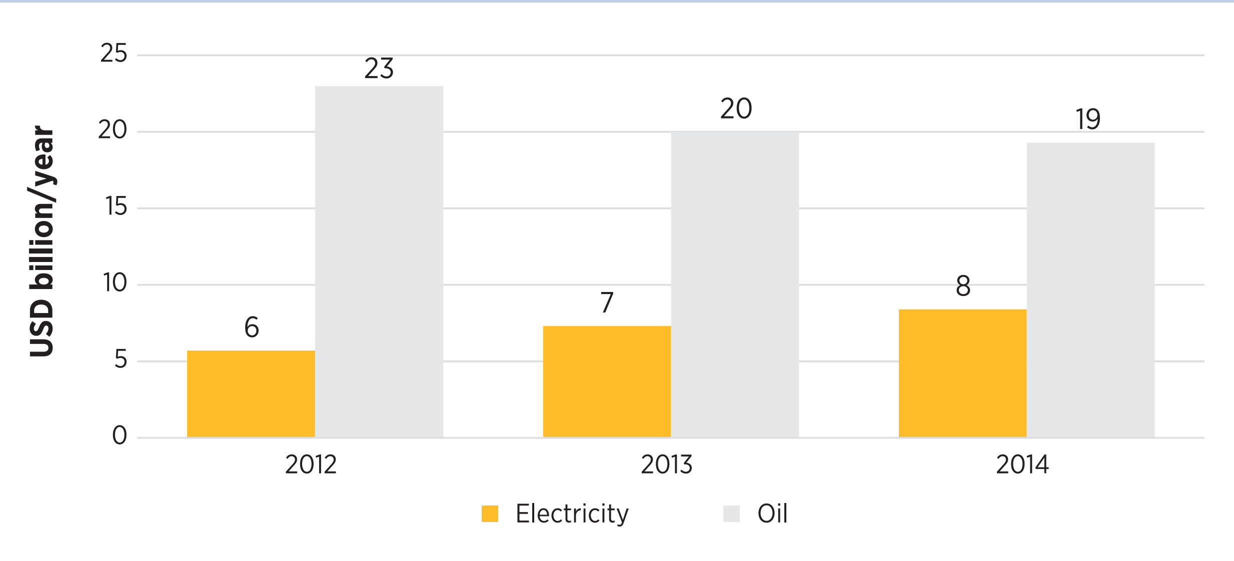
3.3 Energy subsidies

Total energy subsidies in Indonesia were estimated at USD 27.7 billion in 2014 (about 3% of GDP), almost 6% of the USD 493 billion in global subsidies to fossil fuels in the same year (IEA, 2016c). About 70% of subsidies were on oil products (see figure 15), with the remainder spent on electricity (mainly for low-voltage residential, business and industrial connections). Price caps for consumers of diesel, gasoline, LPG and electricity explain the vast majority of subsidies. Due to the difficulties with estimating fossil fuel subsidies, historical estimates for the total subsidy vary somewhat: the Asian Development Bank, for example, estimated the total energy subsidies in Indonesia at USD 36 billion in 2012, compared to USD 29 billion as estimated by the IEA (ADB, 2015b).

More recently, the government has taken active steps to reduce subsidies on oil products, as the country is increasing its reliance on imports of oil products amid declining domestic oil production and increasing demand. Prices for gasoline and diesel prices were first increased by nearly 40% in November 2014. In January 2015 the government announced that subsidies on gasoline would be removed altogether, and that diesel prices subsidies are reduced to a fixed gap of IDR 1000 (about USD 0.08) per litre. Energy subsidies included in the 2016 budget for Indonesia therefore were lowered to USD 4 billion, although it is unclear how this breaks down into subsidies for various energy carriers.

In 2015 the revised state budget included USD 8 billion in energy subsidies (ADB, 2015b). Interestingly, the original allocation for oil subsidies was USD 22 billion in 2015; the reforms, in combination with rapidly falling oil prices, thus had a substantial and immediate effect (IISD, 2015). Outside of subsidies on diesel and gasoline, subsidies on LPG in Indonesia were estimated at nearly USD 4 billion in 2014. The subsidies are applied to the sales of 3 kilogram cylinders, to support energy access for low-income households. LPG use for cooking was supported by the Indonesian government on a large

Figure 15: Energy subsidies in Indonesia, 2012-2014



Source: IEA, 2016c

scale, to mitigate health damages from the use of traditional bioenergy for cooking. Prices for 3 kilogram LPG canisters, which have not changed since 2010, are among the lowest in the world (IISD, 2016).

Electricity subsidies increased until 2014, from USD 5.7 billion in 2012 to USD 8.4 billion in 2014, an increase of 47%. As electricity sales during the same time went up by just 7% (MEMR, 2015), the subsidy on electricity increased from USD 0.033 per kWh in 2012 to USD 0.042 per kWh in 2014 (in nominal terms). This is despite an increase in electricity prices of 15% in 2013, where households consuming 450-900 volt-amperes were not included. Besides increasing sales, escalating prices for fossil fuel inputs and exchange rate revisions are named as main causes for the increasing subsidies on electricity. Apart from price caps, some subsidies to PLN in the form of soft loans and loan guarantees were provided, but they represent only a small fraction of the total (about USD 72 million in 2013) (ADB, 2015b).

During 2014 and early 2015 the government continued to increase electricity prices, mainly for large residential, industrial and governmental users. Electricity prices vary greatly between different types of users, from IDR 415 per kWh (about USD 0.03 per kWh) for small residential users to nearly IDR 1500 per kWh (USD 0.11 per kWh) for large-scale industrial and government users. While the high end of the electricity price range is in line with the market price as estimated by PLN, small-scale users of electricity thus continue to enjoy subsidised tariffs (IISD, 2015).

All in all, the removal of subsidies on gasoline and the large reduction in diesel subsidies, with estimated public savings of USD 15 billion in 2015, shows that the Indonesian government is making progress towards implementing its G20 pledge on phasing out subsidies on energy prices. Important to note is that potential subsidies associated with the government programme to add 35 GW of power generation capacity by 2019, a large part of which is coal-fired, is not (yet) reflected in energy subsidy estimates. It is reported that public finance and guarantees might be included in these plans as well (ODI, 2015).

While the Indonesian law does not allow for the earmarking of specific funds, the subsidy removals have allowed for the development of the Energy Resiliency Fund (Alvionitasari, 2016). The regulation for the framework of this fund is being developed, although it is said that the process is currently on hold. Renewable energy support and rural electrification could be part of the programmes that are envisioned to be supported by this fund, while some of the resources would be set aside to guard against oil price fluctuations.

4 REFERENCE CASE DEVELOPMENTS TO 2030

Key points

- Indonesia has a target for (modern) renewable energy to represent 23% of TPES by 2025. This target is reflected in the National Energy Policy (KEN) scenario of the Energy Outlook Indonesia 2014 and the National Electricity General Plan (RUKN) 2015-2034 from the Ministry of Energy and Mineral Resources, which were used to develop a business-as-usual scenario for 2030 (referred to in this study as the "Reference Case").

- The projections show a strong overall increase in energy use. TFEC increases by nearly 80% in 2014-2030 to reach more than 13 EJ per year. The Reference Case takes Indonesia's modern renewable energy share in TFEC to 16.6% by 2030. In terms of the share of renewables in TPES, the increase is from 8.8% in 2014 to 25.3% in 2030 (based on the "physical energy content" calculation method for TPES). In absolute terms, the use of modern renewable energy increases more than five-fold, up to nearly 2200 PJ per year.

- Power generation increases from 240 TWh in 2014 – including 15 TWh of off-grid generation – to 826 TWh in 2030. The share of renewable energy in total power generation increases to 28.6% – or 236 TWh per year – in the Reference Case. Hydropower accounts for the largest source of renewable power (at 107 TWh per year), followed by geothermal power (62 TWh per year), bioenergy power (32 TWh per year), marine energy (16 TWh per year), solar PV (13 TWh per year) and wind power (6 TWh per year).

- Java-Bali accounts for about 70% of total power generation, but only 16% of renewable power generation, in the Reference Case. Instead, the highest shares for renewable power are in Sulawesi & Nusa-Tenggara and Kalimantan, mainly because of the availability of hydropower. Variable renewable power (solar, wind, marine) accounts for 4% of total power generation, with the highest share in Maluku & Papua (at 15%) due to the ambitious plans there for scaling up solar PV.

- More than 70% of renewable energy use in 2030 is represented by the modern use of bioenergy. Bioenergy use in industry increases in line with the sector's overall increase in energy use, up to 656 PJ, which is more than a doubling from today's levels. In buildings, 602 PJ of bioenergy use is projected for 2030, down from 1620 PJ in 2014. This shift is mainly because of households shifting from using fuelwood for cooking to using electricity and LPG instead.

- In transport, there is a strong increase in the absolute use and relative share of liquid biofuels, as a result of projected B30 and E20 blending mandates from 2025 onwards. Total use of liquid biofuels in transport increases from 57 PJ (1.8 billion litres) in 2014 to 700 PJ (25 billion litres) in 2030, resulting in a 17.2% share for renewable energy in TFEC in transport (from 2.8% in 2014). This could come with significant supply-side challenges; the additional potential for sustainable production from energy crops is limited.

This chapter discusses the Reference Case developments in Indonesia. The Reference Case represents the developments in Indonesia's entire energy system until 2030 based on current government outlooks. The Reference Case for Indonesia is based on three main sources:

- The National Energy Policy (KEN) scenario of the MEMR Energy Outlook Indonesia 2014 was used to generate a business-as-usual outlook for TFEC and the breakdown of fuels consumed therein (MEMR, 2014a).

- The National Electricity General Plan (RUKN) 2015-2034 was used for the Reference Case for the power sector, where five regions were distinguished: Java-Bali, Kalimantan, Maluku & Papua, Sulawesi & Nusa Tenggara and Sumatra (MEMR, 2016a). The revised KEN 2025 targets for the various renewable power technologies were used to derive estimates for the installed power capacity for each by 2030.

- Finally, as the RUKN power generation target for 2030 exceeds the power generation target that is included with the KEN scenario of the Energy Outlook Indonesia 2014, TFEC estimates from the latter were increased, reflecting higher growth in overall energy demand and a higher share of electricity in energy use.

It should be noted that, as table 3 illustrates, there is a significant discrepancy in the outlook for renewable energy in the power sector included in the National Electricity General Plan from MEMR and the latest Electricity Supply Business Plan (RUPTL) from PLN (PLN, 2016). The targets of MEMR for 2025 for all renewable energy technologies – which are taken into account to develop the Reference Case for 2030 – are significantly higher than those as incorporated by PLN into their plans. Therefore the Reference Case 2030, based on the outlook of MEMR, can be considered ambitious in terms of renewable power, although recent policies (*e.g.*, the solar PV feed-in tariff) do indicate the intent of the government to further accelerate deployment.

As shown in figure 16, Indonesia's fuel mix is expected to change significantly in the Reference Case. Of the conventional fuels, the share of natural gas is projected to increase the most, from 12% of TPES in 2014 to 19% in 2030, mainly as a result of increased gas use in industry. The share of oil, on the other hand, will further decline to account for just 20% of TPES by 2030, as its use in power generation decreases while the blending of liquid biofuels (mainly in transport) increases. The share of modern renewable energy will increase from 8.7% in 2014 to 25.2% by 2030. The latter is somewhat higher than Indonesia's renewable energy target for 2025, which is for a 23% share of modern renewable energy in TPES that year. This is due to the continued growth in renewables that is assumed in 2025-2030. Geothermal and modern uses of bioenergy account for nearly 90% of total modern renewable energy use in primary energy terms.

Based on the Reference Case, Indonesia's TFEC will increase to 13 EJ in 2030, an increase of 78% from 7.3 EJ in 2014 (see figure 17). The largest increase is in industry, which will grow by 114% from 2014, to account for 44% of TFEC in 2030. Transport follows with a 100% increase to account for 31% of Indonesia's TFEC in 2030. Energy consumption in buildings increases less, and its share shrinks to 23% of TFEC in 2030. The substitution of traditional bioenergy used for cooking by more efficient cooking fuels explains this trend. Agriculture accounts for the remainder, at about 2% of total TFEC.

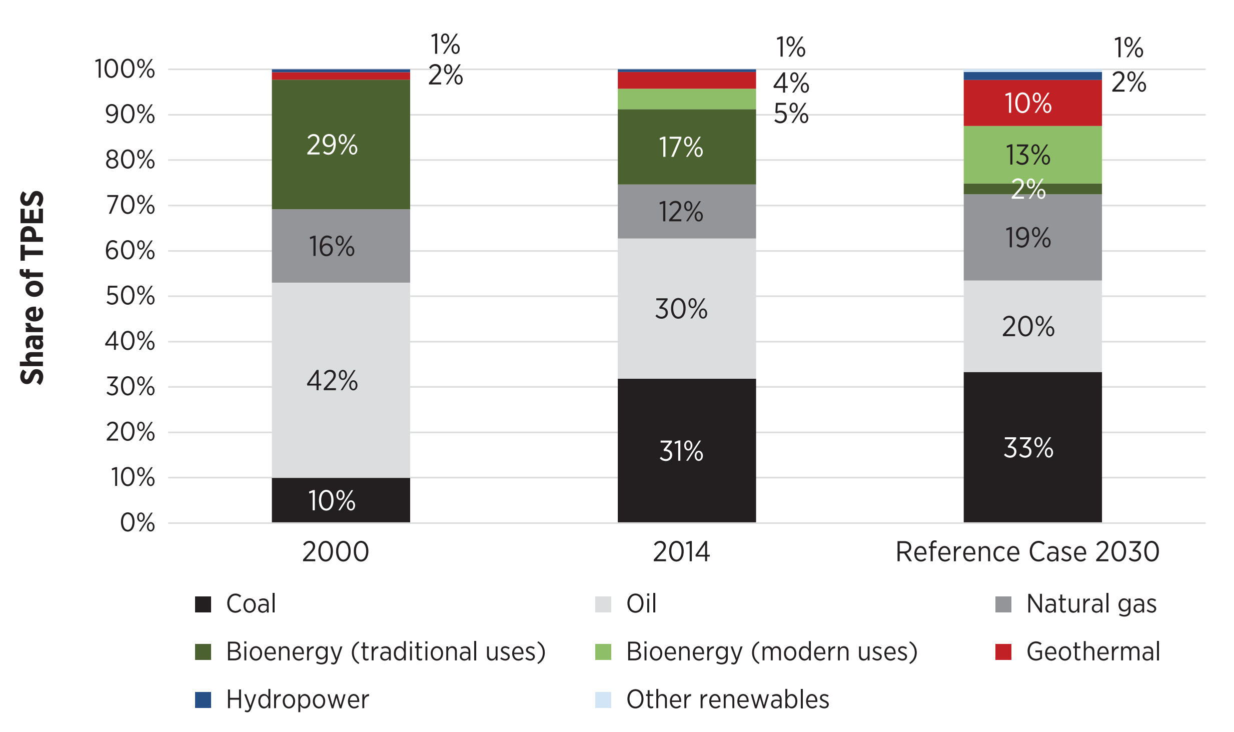
Figure 18 shows the development of the renewable energy shares in TFEC and power generation in Indonesia based on the Reference Case. In total, the share of renewable energy (excluding traditional uses of bioenergy) in TFEC increases from close to 5.8% in 2014 to 16.6% in 2030. This is lower than the share of renewable energy in TPES, due mainly to the low conversion efficiency assumed for geothermal power (10%) as per the physical energy content method.

Table 3: Renewable energy targets included in RUPTL 2016-2025 and in MEMR: Revised KEN 2025

	2025 Target (cumulative capacity in GW)	
	PLN: RUPTL 2016-2025	MEMR: Revised KEN 2025
Geothermal	6.2	7.1
Large hydropower (>10 MW)	13.1	18.3
Small hydropower (<10 MW)	1.4	3.0
Solar PV	0.4*	6.4
Wind	0.6	1.8
Bioenergy	0.5	5.5
Marine energy	0.0	3.1

*The RUPTL 2016-2025 also mentions that there is a plan to develop 5 GW of solar PV by 2025, but this has not been allocated to specific regions. Hence, only the 444 MW that is specifically allocated is included in the table.

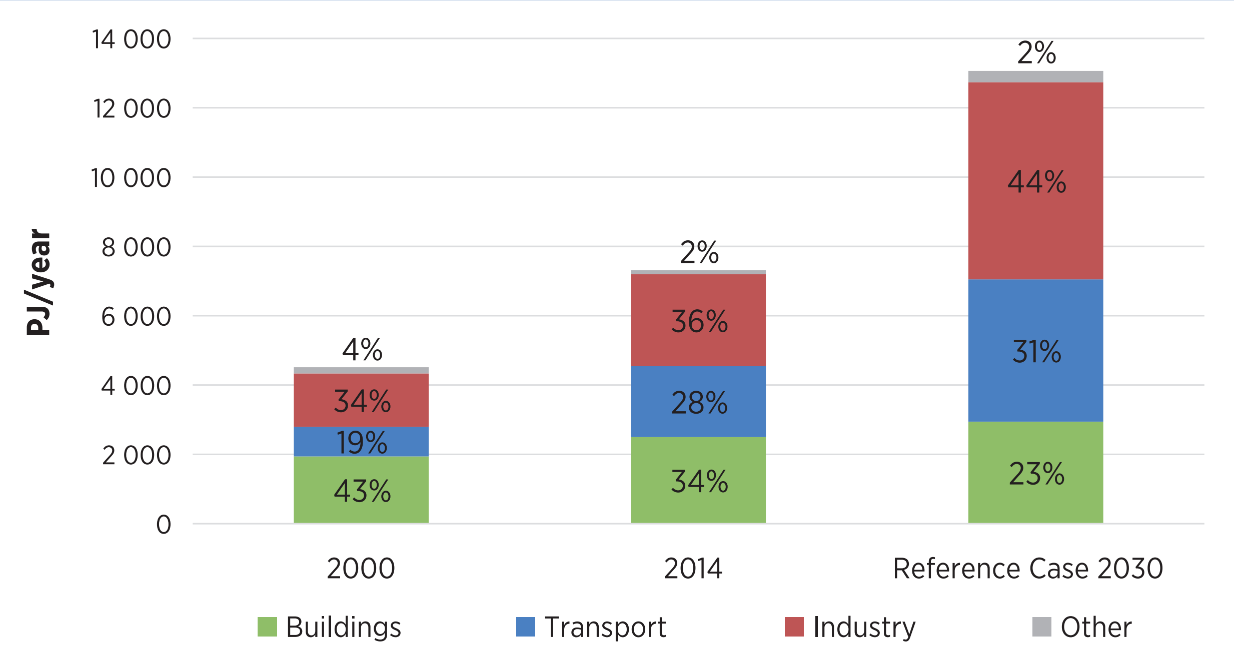
Figure 16: Fuel mix in primary energy supply, 2000, 2014 and in the Reference Case for 2030



Note: the physical energy content method was used to calculate primary energy supply, including a 10% conversion efficiency for geothermal power and 100% for hydropower. These differ from historical conversion efficiencies as applied by MEMR, which are in the range of 16-52% for geothermal power and 23-31% for hydropower.

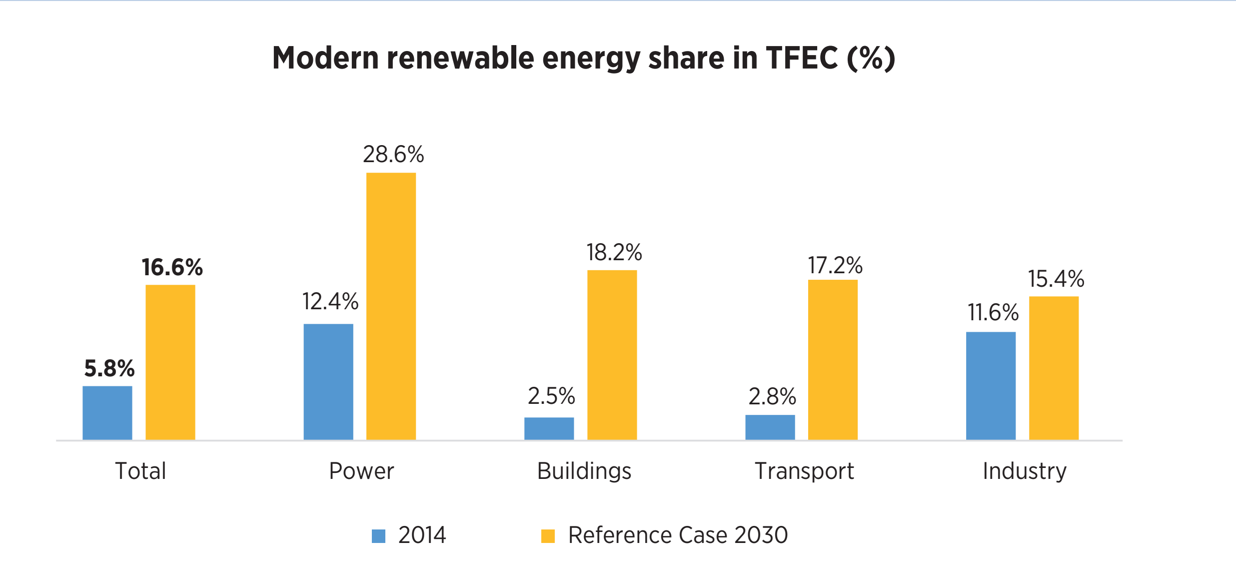
Source: IRENA analysis

Figure 17: Sectoral breakdown of total final energy consumption, 2000, 2014 and in the Reference Case for 2030



Source: IRENA analysis

Figure 18: Modern renewable energy shares in total final energy consumption, power generation, transport, buildings and industry in Indonesia, 2014 and in the Reference Case for 2030



Source: IRENA analysis

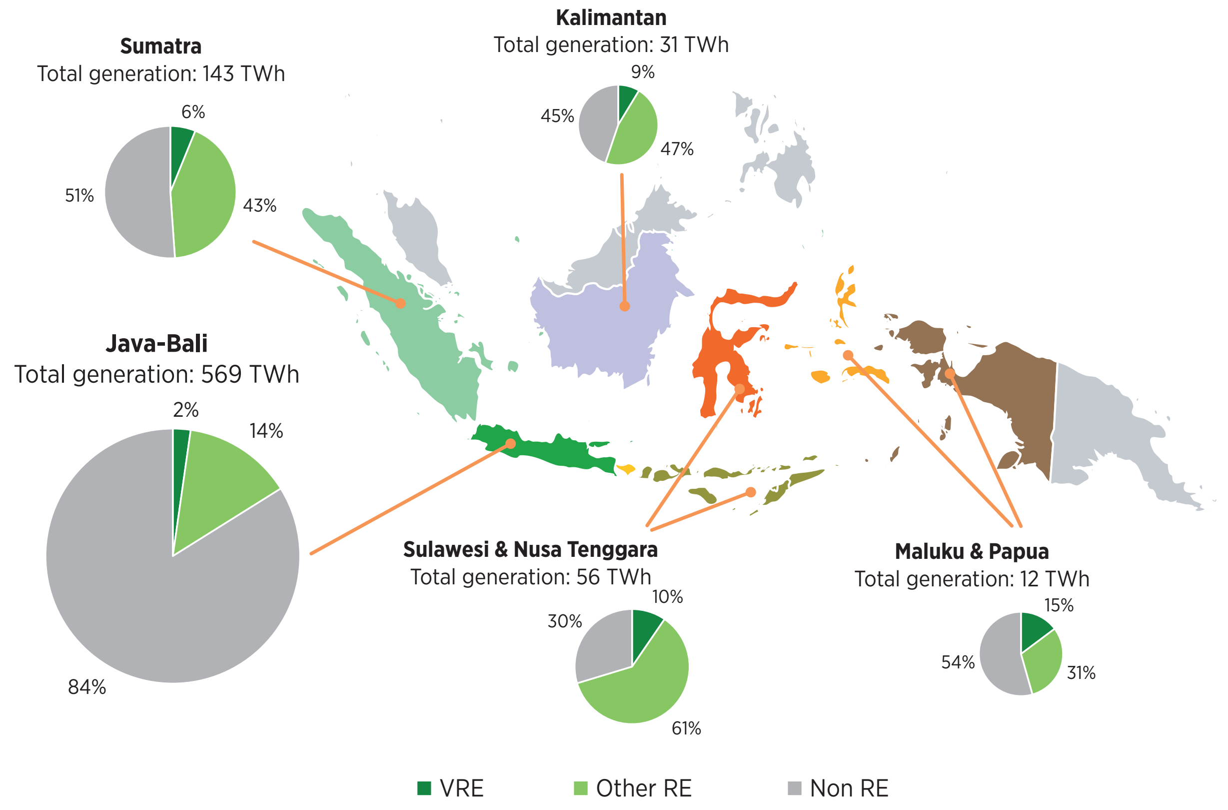
Among the end-use sectors, the largest increase in the share of renewables in TFEC is in buildings: from 2.5% in 2014 to 18.2% in 2030, due to a reduction of traditional uses of bioenergy for cooking and increasing electrification. Without the share of electricity consumption that is generated by renewable power, the share would be just 5.9% by 2030. In transport the share of renewable energy also increases significantly, from 2.8% in 2014 to 17.2% in 2030, due to increasing blending mandates for biofuels. In industry, the renewable energy share increases from 11.6% in 2014 to 15.4% in 2030, due to the increased reliance on bioenergy and electricity for meeting growing energy demand.

The share of renewables in power generation increases from 12.4% in 2014 to 28.6% in 2030. Based on the projections for the various renewable energy technologies, the share of renewable energy in power generation varies among regions in 2030 (see figure 19). Java-Bali, which accounts for 70% of total energy generation in Indonesia in 2030, would have a 16% share of renewables in power generation. In contrast, in Sulawesi & Nusa Tenggara the renewables share is projected to be 71% in 2030, while in Kalimantan it will be 55%. This is due mainly to the fact that most of the hydropower potential that is planned to be exploited is not found on Java-Bali. The share of VRE in power generation will be 4% for Indonesia as a whole, while it is projected to be the highest in Maluku & Papua at 15%, due to a relatively high level of planned installations of solar PV there.

Total power generation increases from 240 TWh in 2014 to 824 TWh in 2030. The share of off-grid power generation decreases in the same time frame, from close to 6% to just 1%. Renewable power generation increases more than eight-fold, from 29 TWh in 2014 to 235 TWh in 2030. This includes both on-grid and off-grid generation, with the latter including mini-grids and off-grid solutions based on solar PV, micro hydropower and bioenergy power used exclusively for own consumption. Off-grid renewable power generation accounts for less than 5% of total renewable power generation in 2030.

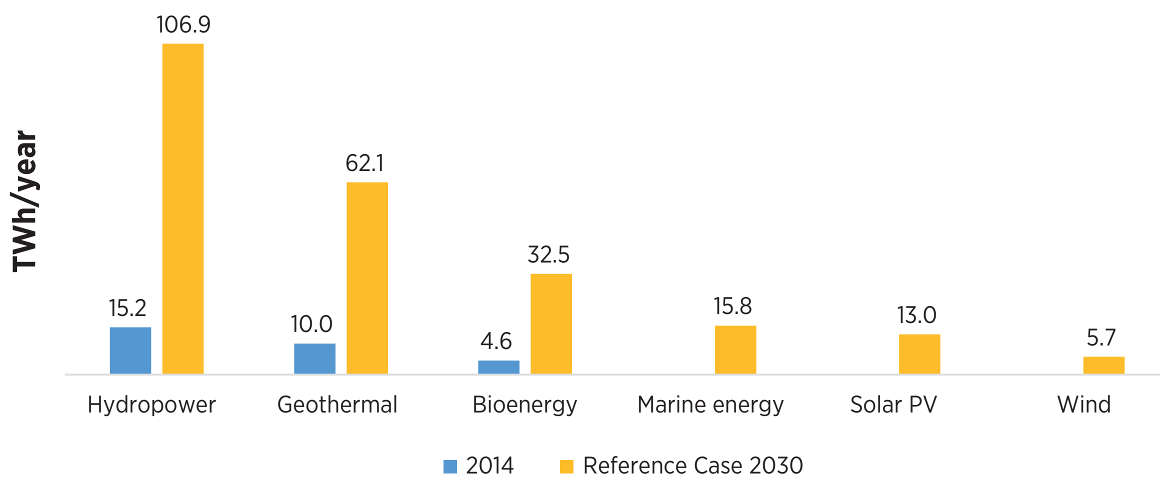
Hydropower maintains the largest source of renewable power generation at 106.9 TWh in 2030, representing a more than six-fold increase from 2014 (see figure 20). Geothermal generation (62.1 TWh in 2030) and bioenergy (31.3 TWh) grow five-fold and six-fold from 2014, respectively. Finally, VRE generation technologies are projected to account for nearly 35 TWh by 2030 (about 4% of total power generation), explained by 15.8 TWh of marine energy, 13 TWh of solar PV and 5.7 TWh of wind energy. The significant contribution of marine energy is due to the ambitious outlook for the technology in the revised KEN targets (3.1 GW by 2025)

Figure 19: On-grid power generation in the Reference Case for 2030



Source: IRENA analysis

Figure 20: Renewable power generation in Indonesia, 2014 and in the Reference Case for 2030



Source: IRENA analysis

and to its relatively high capacity factor (40%). Lower average capacity factors – in addition to the respective KEN targets (see table 3) – for solar PV (16%) and wind power (25%) explain their more modest contributions.

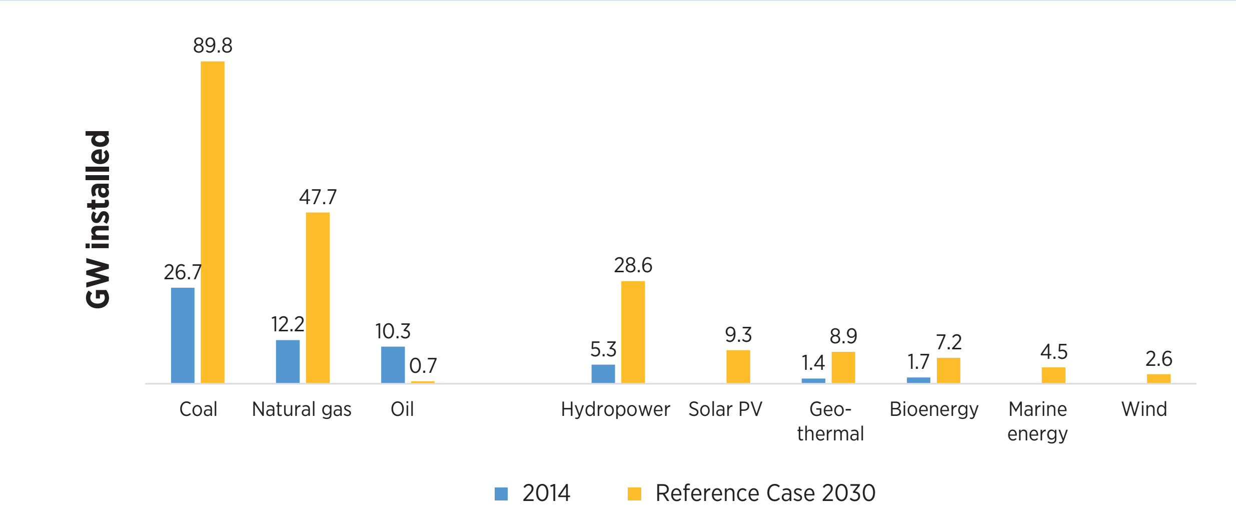
In the Reference Case there will be 199 GW of power capacity, of which 138 GW is conventional and 61 GW is renewable generation capacity (see figure 21). Coal will continue to account for most of the installed power generation capacity at nearly 90 GW, implying annual installations of nearly 4 GW per year until 2030. Only 700 MW of on-grid diesel power generation capacity (500 MW of which is off-grid) is assumed in the Reference Case for 2030. Of the renewable technologies, hydropower will have the highest installed capacity at 28.6 GW, followed by solar PV at 9.3 GW.

The transport sector is projected to have the second highest share of renewable energy in final energy consumption by 2030 at 17.2%. Out of 894 PJ of total liquid biofuels consumption by 2030 (see figure 22), 699 PJ (or nearly 80% of the total) will be consumed in transport. This projection is based on the blending mandates of 20% for ethanol and 30% for biodiesel targeted for 2025, which are assumed to be maintained until 2030. As a result, about 13 billion litres of biodiesel and 12 billion litres of ethanol are required to meet these targets. This represents a big increase; for 2016 the targeted domestic biofuel consumption is estimated at around 3.2 billion litres of biodiesel. Electric mobility remains minimal in the Reference Case at just 15 PJ, or 0.4% of transport TFEC. The contribution to total renewable energy use in transport from renewable power generation is therefore small at around 0.1%.

In buildings, 602 PJ (35 million tonnes) of bioenergy use is projected for 2030, down from 1620 PJ (95 million tonnes) in 2014. The shift is due in particular to a decrease in the number of households relying on fuelwood for cooking: from around 24 million households in 2014 to an estimated 8 million by 2030. Traditional uses of bioenergy for cooking would still account for nearly 90% of total bioenergy used in buildings in 2030. The remainder consists mainly of commercial use of liquid biofuels, and an estimated 2 million households using biogas digesters for cooking. The reduction in bioenergy use is explained mainly by the increase in LPG and electricity for cooking. LPG is estimated to be the primary cooking fuel for 70% of households in 2030 (up from 62% today), while 19% of households use electric cooking (compared to 2% in 2014).

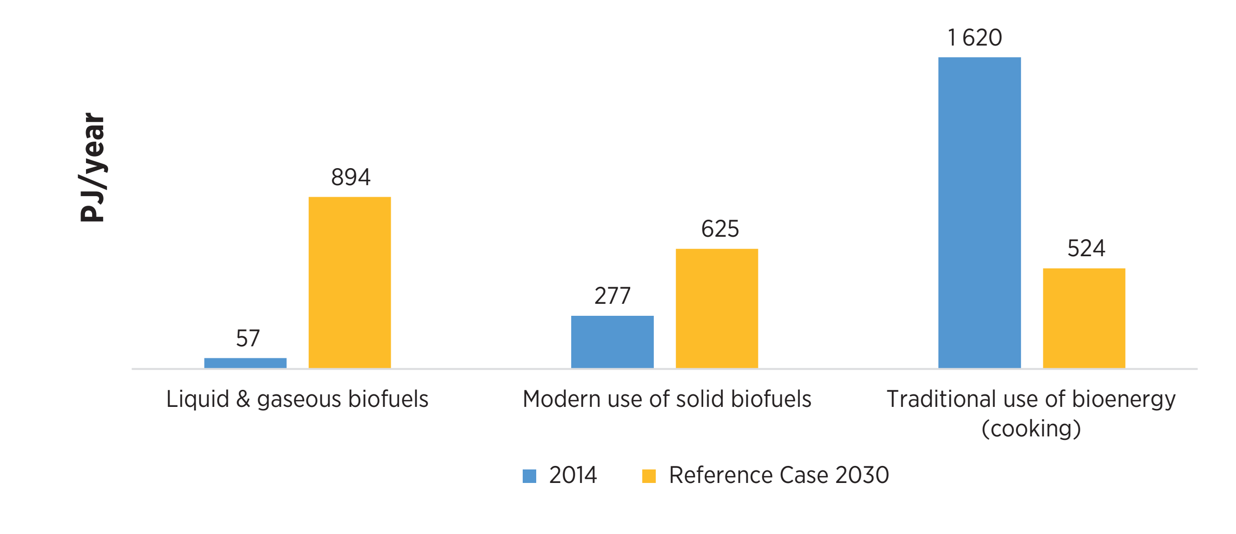
Industrial energy demand for process heat generation will increase to 4.9 EJ by 2030, up from 2.4 EJ in 2014. The implied annual growth is 4.6%, in line with historical growth in industrial heating demand (5% per year between 2010 and 2014). Bioenergy use in industry increases to 656 PJ (39 million tonnes), an increase of 240% from 2014. More than 90% of bioenergy use consists of solid biomass (91%), with the remaining 9%

Figure 21: Total installed power generation capacity in Indonesia, 2014 and in the Reference Case for 2030



Source: IRENA analysis

Figure 22: Reference Case growth of renewable energy use in end-use sectors in Indonesia, 2014 and 2030



Source: IRENA analysis

coming from liquid and gaseous biofuels. The share of bioenergy in total heating demand is projected to increase modestly in the same time frame, from 11.5% in 2014 to 13.3% in 2030. Paper, pulp and printing, as well as cement, ceramics, bricks and food continue to be key industrial sectors for energy use in industry. Combined they account for about one-third of total industrial bioenergy use in 2030.

5 RENEWABLE ENERGY POTENTIAL AND COST

5.1 Power generation

Based on available data, an estimated 716 GW of theoretical potential for renewable energy-based power generation has been identified in Indonesia (see table 4). The potentials shown take into consideration the supply-side constraints of resource and land availability, but not other constraints such as limitations imposed by insufficient power demand nearby and/or transmission networks. Therefore, capturing all of these resources is unlikely to be feasible, but these figures do provide an indication of the magnitude of the total potential. The figures provided are based on the resource potential identified in existing studies; for marine and wind, such resource mapping is ongoing and therefore their theoretical potential is likely to be higher than what is shown.

Five regions have been distinguished to develop an understanding of where the theoretical potential is based and how this correlates with the demand for power and the projected renewable energy deployment for each region in the Reference Case. Sumatra, Kalimantan and Maluku & Papua together account for more than 75% of the renewable energy power potential. Java-Bali is where 70% of power demand will be in 2030, while it has direct access to only 10% of the total renewable potential for power generation in Indonesia.

Based on the potential for each of the regions and on available roadmaps for some of the renewable technologies (*e.g.*, solar PV, hydropower, geothermal), the second column in table 4 shows what the assumed renewable power capacity for each of the regions is in the Reference Case for 2030. Comparing these planned deployment levels with the theoretical potential per renewable resource and the total demand for power in each of the regions provides the initial basis for the estimation of the REmap Options. However, important constraints and other considerations also are taken

Table 4: Renewable power capacity in the Reference Case for 2030 and the total potential of renewable power

GW	Reference Case 2030		Theoretical potential for renewable power capacity	Theoretical potential by renewable energy power technology						
	On-grid power capacity	**On-grid renewable power capacity**		Solar PV	Large hydropower	Small hydropower	Bioenergy	Geothermal	Marine energy (tidal)	Wind (onshore)
Total Indonesia	**193.5**	**55.8**	**716.4**	**532.6**	**75.0**	**19.4**	**32.7**	**29.5**	**18.0**	**9.3**
Sumatra	**39.2**	**17.6**	**196.2**	137.1	15.6	5.7	15.6	12.9	8.3	1.0
Java-Bali	**119.8**	**19.1**	**71.5**	38.7	4.3	2.9	9.2	10.1	2.4	3.9
Kaliman-tan	**10.3**	**5.4**	**184.2**	149.0	21.6	8.1	5.1	0.2	–	0.3
Sulawesi & Nusa Tenggara	**20.3**	**11.6**	**97.6**	66.8	10.8	1.8	2.6	4.8	6.9	3.9
Maluku & Papua	**3.9**	**2.1**	**166.8**	140.9	22.8	0.8	0.2	1.5	0.4	0.3

Source: IRENA analysis and inputs received from MEMR during the REmap Workshop in Jakarta, 1 April 2016 into account in their derivation; an overview of this by technology is provided next.

Solar PV

Solar PV has the highest resource potential in Indonesia at 532.6 GW, explained by the high solar resource across Indonesia, which is in the range of 4.0-6.9 kWh/m^2 and averages 4.8 kWh/m^2 (Veldhuis and Reinders, 2013). The estimated potential for different regions is partially a result of these differences in resource across the country (which is somewhat higher in the eastern part of the country), but is mainly an outcome of differences in the availability of land and rooftops (IRENA, n.d.).

Solar PV is expected to be used on a significant scale by 2030 in three ways: in utility-scale plants, on residential and commercial rooftops, and in off-grid settings for electrification in remote areas or to displace costly diesel-powered generation. The off-grid potential for solar PV has been estimated by MEMR at 2.1 GW, with the largest potential represented by Maluku & Papua (0.95 GW) and Sulawesi & Nusa Tenggara (0.42 GW)[9]. In the Reference Case, it is assumed that this potential will have been fully exploited by 2030 through active efforts by the government and PLN to use solar PV to provide electricity to 1.1 million households currently not electrified.

With an overall target of 6.4 GW of solar PV installed by 2025, the Reference Case for 2030 assumes that the market continues to grow until 2030 to reach 9.3 GW of installed capacity in that year. With 2.1 GW of this assumed to be related to the off-grid solar segment, 7.2 GW is allocated to grid-tied solar PV. As the theoretical potential for solar PV exceeds 500 GW, this implies that less than 1% of this will be captured by 2030, despite abundant potential across the different regions of Indonesia.

From the distribution of daily electricity demand throughout the day, it becomes obvious that there is a relatively sharp evening peak, explained mainly by the use of rice cookers at that time (see figure 23). This might limit the potential for renewables and in particular solar PV (without any storage), due to the mismatch between the peak in demand and the time of day when solar PV produces at its peak. However, the anticipated rapidly increasing demand for cooling in buildings (from 29% of electricity consumption in 2014 to 35% in 2030) is likely to flatten electricity demand, increasing the opportunity for solar PV to match electricity demand in buildings.

9 These calculations include an estimate of the future electricity use per household at 1.8 kW, which is significantly higher than current levels of electricity use in rural households. Due to this conservative assumption – in terms of not underestimating future electricity needs – on the part of MEMR, this implies that the deployment of off-grid solar PV in terms of power capacity could thus be lower.

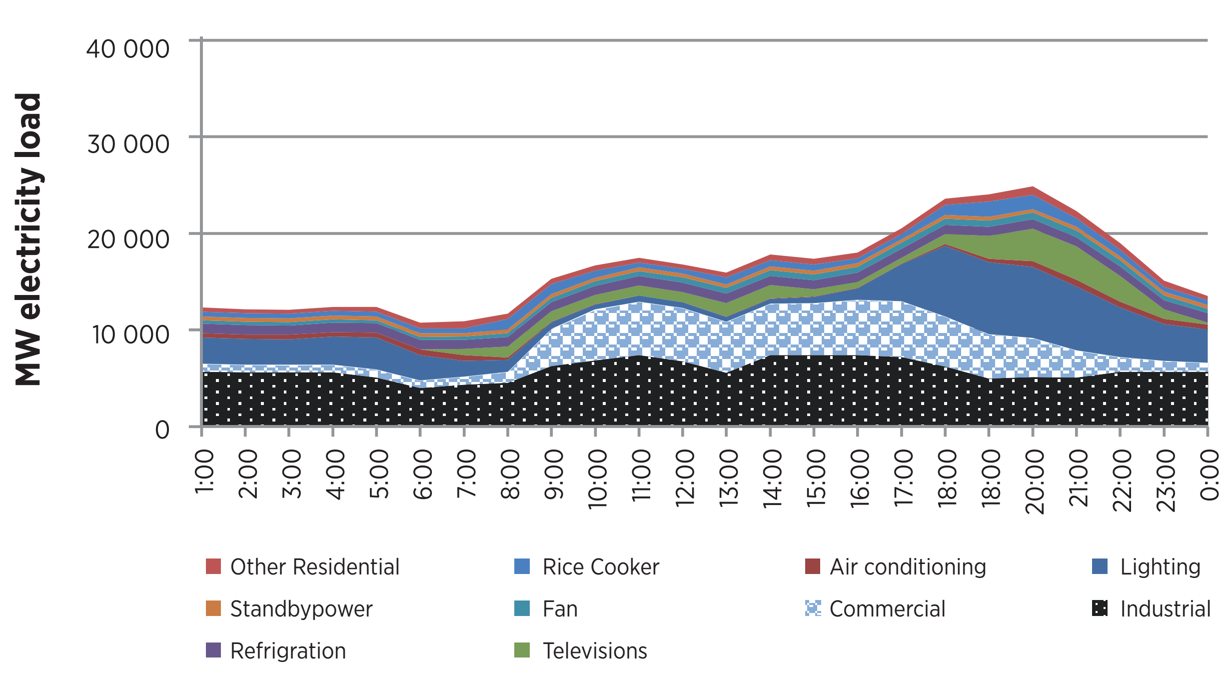
Hydropower

Based on a study of 1249 locations, the resource potential for large hydropower in Indonesia has been estimated at 75 GW (MEMR, 2016c). Of this, 18.3 GW is targeted for exploration until 2025 (MEMR, 2016d). In the Reference Case this will increase further to 24.3 GW by 2030, nearly one-third of the total potential. Table 4 shows, however, that nearly three-quarters of the potential is based in regions with lower levels of power demand: Kalimantan, Sulawesi & Nusa Tenggara and Maluku & Papua. Indeed, these regions combined account for only 12% of the estimated power generation in Indonesia in 2030. Lacking a detailed deployment roadmap for large-scale hydropower, it is therefore assumed in the Reference Case that all of the potential in Java-Bali and about 60% of the potential in Sumatra already have been captured by 2030.

For small hydropower the potential was estimated at 19.4 GW, most of it in Kalimantan (42% of total resource) and Sumatra (30% of total resource). In the Reference Case, about 20% of the total potential for small hydropower, or nearly 4 GW, will be grid-connected by 2030. Another 300 MW is assumed to be used off-grid or in mini-grids.

It is important to note that a large share of the hydropower resource is based in protected forest areas or might come with a high number of resettlements. In a 2011 study that focused on 26 GW of existing, planned, ongoing and potential projects (which all passed the third screening of the Second Hydro Power Potential Study conducted in 1996-1999) it was estimated that only 8 GW could be developed by 2027 if no projects located in protected areas would be considered. A "policy-oriented scenario" estimated that 14.8 GW would be developed by the same year, but 20 projects would be located in protected areas (MEMR, PLN and JICA, 2011). Others have estimated the economically

Figure 23: Modelled daily electricity demand in Indonesia in 2010



Source: SEAD, 2015

feasible hydropower potential at 40 TWh/year, or around 10 GW (IHA, 2015). Clearly the hydropower targets set by the government are ambitious in light of these considerations.

Bioenergy

The total potential for power generation from bioenergy is estimated at 32.7 GW, nearly half of which is on Sumatra (MEMR, 2016b). Palm oil represents about 12.7 GW of the total potential, with the remainder coming from rice husk (9.8 GW), natural rubber (2.8 GW), municipal solid waste (2.1 GW), corn (1.7 GW), solid wood (1.3 GW), sugar cane (1.3 GW), cow dung (0.5 GW), cassava (0.3 GW) and coconut (0.2 GW). In the Reference Case, 7.2 GW, or about 22% of the potential, is utilised by 2030. With the government's ambition to increase bioenergy power generation on the grid, the assumption is that 60% of the installed capacity will be grid-tied, with another 40% used for captive power.

Geothermal

An estimated 40% of the world's geothermal reserves are found in Indonesia, and the potential use for power generation is estimated at 29.4 GW (MEMR, 2016e). Of the total potential, 1.4 GW has already been exploited (1.2 GW of which is on Java), 17.2 GW is labelled as "reserve" (which implies that it is based on a detailed investigation), and 12.2 GW is classified as "speculative and hypothetical resource". Given that a large number of possible sites are found in forest areas, and since their assessed potentials could be overestimated, the country's realistic deployment potential by 2030 might be lower (ADB and World Bank, 2015). The government target for 2030 – included in the Reference Case – is to reach 8.9 GW of geothermal power capacity. Based on detailed plans until 2025, most additional capacity is expected in Java-Bali (5.3 GW by 2030 in the Reference Case), which is home to about one-third of the total geothermal potential and nearly 40% of the currently unexploited "reserve" of 17.2 GW. Next is Sumatra (3.0 GW installed by 2030 in the Reference Case), which is also where the highest resource potential is found, at about 44% of the total.

Marine energy

Marine energy is an emerging technology, with 547 MW installed globally by the end of 2015 (IRENA, 2016d). While none of this was based in Indonesia, the government has set a target to reach 3.1 GW of installed marine energy capacity by 2025 (MEMR, 2016d). This can be considered ambitious given the immaturity of the technology. In the Reference Case, it is assumed that the market would continue with the same level of deployment in 2025-2030 as before, and the installed capacity would reach 4.5 GW by 2030.

As of today only the potential of ocean currents has been measured. The total potential (from 10 locations) of tidal energy has been estimated at 18 GW (MEMR, 2016f). The Riau islands (included with Sumatra in table 4) and the Alas Strait (in Western Nusa Tenggara) account for nearly 12.6 GW, or about 70% of the total tidal potential. While current velocity across the locations varies from 1.39 to 3.00 metres per second (or 1.38 to 13.84 kW/m^2) this lasts for only about two hours of the day, which in combination with the remoteness of key resources limits the potential of tidal energy. Ocean Thermal Energy Conversion (OTEC) – which uses the difference in temperature between (cooler) deep and (warmer) surface water to generate electricity – is thought to have high potential as well, even though the exact resource has not been assessed in detail yet. Therefore, the assumptions for the Reference Case are based on the tidal energy potential alone, with most of the installed capacity by 2030 estimated to be on Java-Bali (2.1 GW) and Sumatra (1.7 GW).

Wind

The total potential for onshore wind energy was estimated at 9.3 GW in Indonesia (MEMR, 2016g). Of this, about 960 MW has been identified as ready for development immediately, with half of this found to be on Java-Bali and another 25% on Sulawesi. Measurement of the wind resource was first started by the National Institute of Aeronautics and is ongoing, with 171 sites evaluated up to now at a typical measurement height of 50 metres. Based on the distribution of the evaluated sites and the identified short-term potential across wind locations, it is estimated that nearly 85% of the wind power potential is on Java-Bali, Sulawesi and Nusa Tenggara. The government targets 1.8 GW of installed wind capacity by 2025, with capacity factors estimated at 20-30%.

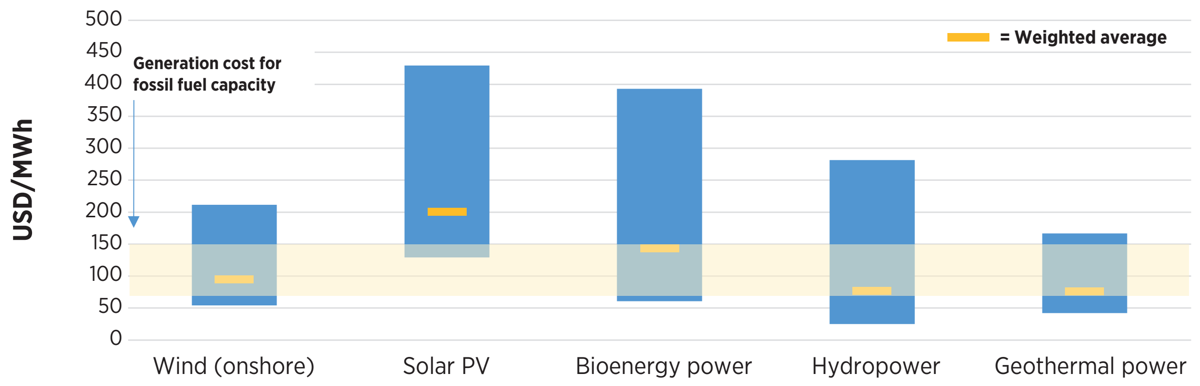
The Reference Case assumes that the level of deployment continues at the same pace as before. Hence, the installed capacity further expands to 2.6 GW by 2030, 28% of the total potential identified so far. Most of this (74%) is assumed to be on Java-Bali, given the combination of good wind resources (many sites with more wind speeds above 6 metres per second, mainly along the coastline) and high electricity demand (IRENA, n.d.). Offshore wind energy thus far has not been included in Indonesia's renewable energy ambitions. Its application is not considered viable at present, given that the potential is mainly in the Indian Ocean, where costs are anticipated to be high due to the sea depth.

Generation cost

There is a wide range in the estimated cost of renewable power generation in Indonesia across technologies, depending on the type of application, project size and capacity factors (see figure 24). The wide ranges across technologies are explained by the difference in cost encountered for larger-scale projects in easily accessible locations (*e.g.*, on Java) and smaller projects in remote locations. Generally, hydropower and geothermal have some of the lowest generation costs. For geothermal power this is explained by the high capacity factor (about 80% historically), even though there is a wide range in project capital cost that is site-specific. For hydropower the capacity factor is lower in Indonesia (historically at 33-37%), but large-scale projects come at a relatively low cost per installed kW. New projects in perhaps less-suitable locations than those exploited to date are likely to come with higher project cost, however. For bioenergy power the main variables explaining the spread in the estimated generation cost are the project capital cost, which varies significantly by case, and the estimated capacity factor. For captive power, the latter is assumed to be just 26% based on historical data, while for on-grid bioenergy power, based on the average observed capacity factor for the Asia region (excluding China), this is assumed to be 66%.

Wind (onshore) and especially solar PV show considerable ranges in generation cost, explained by their application (grid-tied versus off-grid in remote

Figure 24: Current range and weighted average levelised cost of electricity for various types of power generation in Indonesia



Source: IRENA analysis

locations), project size (utility-scale versus small distributed cases) and resource differentials (especially in the case of wind). The costs for new larger-scale solar PV projects are likely to be at the lower end of this range, or even below. This is because the estimates shown are based on completed projects, which often have incurred learning costs since (larger-scale) solar PV projects are still relatively rare in Indonesia. Furthermore, there exists large potential for global cost reductions for solar PV, and the levelised cost for Indonesia – also considering the country's relatively high levels of insolation (16% average capacity factor) – could be much lower as the local industry and market mature.

In general, in comparing the cost ranges for renewables with the current cost of non-renewable power generation, it is clear that the potential for deployment in Indonesia based on competitive grounds already exists for renewable energy power. The business case for renewables will only strengthen based on further cost reductions and technology innovations.

5.2 Bioenergy

Supply potential

Bioenergy is a key resource for all types of energy in Indonesia, including heating, power generation and transport. Based on historical data on agricultural and forestry production in Indonesia, the technical potential for residues for bioenergy was estimated at 756 PJ (see table 5). Palm oil, rice and sugar accounted for nearly half of the potential for using agricultural residues, while residues in the wood industry accounted for nearly 60% of total forestry residue potential. However, many other potential feedstocks for bioenergy in Indonesia have been identified that are not included in this assessment, including *jatropha curcas*, *pongame pinnata*, *calophyllum inophyllum* (nyamplung), and candle nut (for biodiesel production) and sago, sugar palm, cassava and sorghum (for ethanol production) (Prastowo, 2011).

Used cooking oil also could be used to supply increasing biodiesel production targets, with the minimum potential availability from food processors estimated at 84 000 tonnes per year, while the potential collections from restaurants and food stall vendors adds another 562 364 tonnes per year (Ecofys, 2013). Currently about 120 000 tonnes of used cooking oil are collected by Indonesia's three main collectors, and smaller collectors gather another 65 000 tonnes. The large collectors export the oil (mainly to the EU), where most of it is already being used for biodiesel production. Small collectors are using a majority of the used cooking oil for non-energy purposes.

For biogas in households, the potential for usage in Indonesia was estimated at 1 million household bio-digesters, based on a feasibility study by the Netherlands Development Organisation (SNV) in 2008 that took

Table 5: Technical potential of various types of agricultural and forestry residues in Indonesia, 2010

Agricultural residue	Residue type	Planted area (2010)	Yield (MJ/ha/year)	Technical potential (PJ)
Palm oil		8 430 026		**193.1**
	Fruit empty bunches		32 800	138.3
	Palm shell		6 500	54.8
Coconut		3 808 263		**40.7**
	Shell		9 600	17.5
	Fibre		12 700	23.2
Rubber	Small log	3 445 121		**36.3**
Sugar	Bagasse	448 745	288 800	**129.8**
Rice	Husk	12 147 637	11 800	**143.3**
Corn	Cob	4 131 676	17 300	**71.5**
Solid agricultural biomass				**614.6**

Forestry residue	Years	Residues (Million tonnes/year)	Technical potential (PJ)
Log-cutting residues	1998-2010 average	3.7	**15.6**
Saw timber	2006-2010 average	4.2	**42.0**
Wood industry	2006-2010 average	7.9	**83.8**
Solid forest biomass			**141.5**

Note: the table shows total technical potential from bioenergy resources for all sectors in 2010; the estimates for GW of power generation as mentioned in section 5.1 therefore are included in these numbers

Source: Prastowo, 2011

into account both supply- and demand-side factors. By 2030 the potential could be significantly higher. Farmers on Java especially could substantially reduce spending on cooking fuels by switching to biogas, although awareness in the communities of the potential returns is lacking (World Bank, 2013). In additional, the easily available potential for biogas in industry based on palm oil mill effluent is estimated at 32 PJ per year today (Stichnothe, 2016).

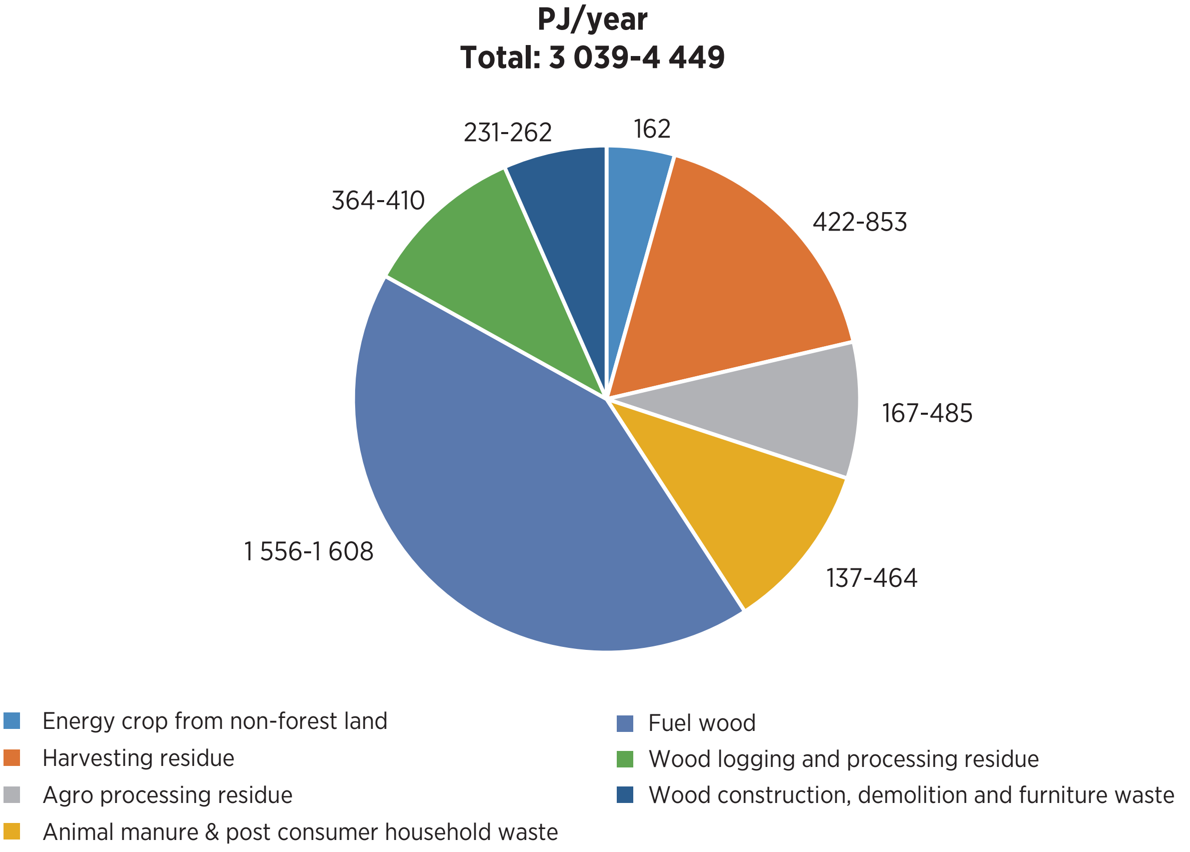
For 2030, IRENA estimates that the total sustainable bioenergy supply potential in Indonesia ranges from 3 039 PJ to 4 449 PJ per year (see figure 25)[10]. The highest potential is for fuelwood at 1 556 PJ to 1 608 PJ per year. This indicates that there is enough fuelwood available that is suitable for use in modern bioenergy cook stoves, and can be collected without anticipated effects on land-use change. The potential for wood residue (logging and processing) and wood waste (construction, demolition and furniture) ranges from 595 PJ to 673 PJ per year, significantly higher than the estimate based on historical data. This is due in part to the included potential of recycling wood waste (231-262 PJ per year), which is not included in the estimates in table 5, as well as rising levels of production until 2030.

The potential for agricultural residues (harvesting and processing) is estimated at 589 PJ to 1 338 PJ per year. The average of the range (963 PJ per year) is about 50% higher than the estimate for 2010 as provided in table 5, explained in part by the increasing levels of agricultural production expected until 2030. The potential for animal manure and waste by 2030 is estimated at 137-668 PJ per year. This includes the potential for using palm oil mill effluent as biogas, which is estimated to range from 119 PJ to 204 PJ per year in 2030, based on the current potential for biogas and a range in the growth projection for palm oil production in Indonesia.

Energy crops from non-forest land have a more limited potential by 2030, at 162 PJ per year, which is estimated as the current production of energy crops (palm oil for biodiesel) increased by the expected yield increase of

10 A full explanation of IRENA's methodology for assessing bioenergy supply potential can be found at *https://www.irena.org/remap/IRENA_REmap_2030_Biomass_paper_2014.pdf*

Figure 25: Primary bioenergy supply potential in Indonesia, 2030



Note: sizes as shown in circle diagram are based on an average of low and high estimates
Source: IRENA analysis

0.7% per year. Given the government moratoriums on palm oil concession (which should be in effect until 2021), as well as the expansion of agricultural lands to meet the increasing demand for food and palm oil, no additional land is assumed to be available sustainably for energy crops until 2030.

Estimates for the potential of bioenergy supply in Indonesia vary based on methodology and the assumptions made. Table 6 shows the potentials as estimated by IRENA, and as found in other literature. For residues, IRENA's estimates are within the range as estimated before. A recent study estimated the sustainable potential from palm oil residues in Indonesia at 491 PJ (mainly from trunk and fibre) in 2030 in a business-as-usual scenario (IEE, 2016). This seems to be in line with IRENA estimates for agricultural residues (589 PJ to 1338 PJ) for the same year, when taking into account the bioenergy potential of residues from other crops as well. For energy crops, IRENA's estimate for the potential is somewhat higher than what was found in the literature, which is due to the fact that energy crops (biodiesel from palm oil) already have increased significantly in recent years beyond the sustainable supply potential that was estimated historically.

One area for potential that is not included in IRENA's assessment is for woody crops on surplus and marginal agricultural land, which could be used for the production of advanced biofuels. Based on existing literature, the potential for this category is estimated at 1008 PJ to 3321 PJ per year. Given the rapid increase in liquid biofuel demand and the relatively limited potential for sustainable energy crops, advanced biofuels from woody crops might present an opportunity towards meeting

Table 6: Bioenergy supply potential in Indonesia based on IRENA estimates and literature review

	Other literature		IRENA
Agricultural biomass, land dependent (PJ)	**Low**	**High**	**Average**
Woody crops on surplus agricultural land	726.0	1234.0	
Woody crops and grasses on marginal land	282.0	2 087.0	
Total perennial lignocellulosic feedstocks	**1 008.0**	**3 321.0**	
Other first-generation biomass resources (PJ)	**Low**	**High**	**Average**
Oil crops on marginal/degraded land	5.1	35.0	
Sugar cane	13.0	69.0	
Total first-generation crops	**18.1**	**104.0**	**162.4**
Residues, land independent and current data (PJ)	**Low**	**High**	**Average**
Forestry industry processing residues (primary mill)	26.0	59.0	
Forestry industry processing residues (secondary mill)	0.0	30.0	
Logging and site-clearing residues	75.0	223.0	
Forest thinning / fuel treatments	820.0	5 360.0	
Total forestry residues	**921.0**	**5 672.0**	**2 215.9**
Agricultural residues, land independent (PJ)	**Low**	**High**	**Average**
Crop residues	15.0	1 476.0	
Wasted grain	0.0	20.0	
Food processing residues	0.0	0.0	
Livestock manure	1.0	290.0	
Municipal solid waste, landfill gas	0.0	48.0	
Total agricultural residues	**16.0**	**1 834.0**	**1 365.9**
Total bioenergy supply potential in Indonesia (PJ)	**1 963.1**	**10 931.0**	**3 744.2**

Source: IRENA analysis and literature review from Batidzirai et al., 2012

blending targets while ensuring the sustainability of the bioenergy feedstock supply chain.

Supply cost

The supply cost of bioenergy feedstock in Indonesia is estimated to range from as low as USD 1.1 per GJ for agricultural processing residues, to USD 18.9 per GJ for wood residues and waste (see table 7). The average cost of supply of bioenergy in Indonesia is USD 9.7 per GJ, taking into account the feedstock mix. Comparing these supply costs with prices for fossil fuel products in Indonesia, a few things stand out.

First, the supply cost of energy crops from forest land is high compared to the subsidised price of 3 kilogram LPG canisters which are used by many smaller households for cooking. Comparing the 3 kilogram canister LPG prices with the (unsubsidised) 5 kilogram canister LPG prices also shows the extent to which they are subsidised (close to 60%). Without the subsidies, modern bioenergy cook stoves would offer a much better economic case to potential buyers, as would solar thermal collectors.

Second, steam coal prices in Indonesia are at low levels, but the supply cost of agro-processing residues and animal manure and post-consumer household waste are in fact lower. The use of harvesting residues, for which significant potential has been identified, is likely to be competitive when used to substitute petroleum products and natural gas in industry. Natural gas prices paid by industry are relatively high in Indonesia. It was reported in March 2016, for example, that the ceramics industry in Indonesia paid on average USD 9.1 per million thermal units (mBtu) for natural gas, compared to around USD 3.0 per mBtu in countries such as Singapore and Thailand (Sinaga, 2016).

Table 7: Supply cost for bioenergy feedstock in Indonesia in 2030, and prices of selected fossil fuel products

	USD/GJ
Energy crop from non-forest land	12.1
Harvesting residue	4.7
Agro-processing residue	1.1
Animal manure and post-consumer household waste	1.5
Fuelwood	11.7
Wood logging and processing residue	18.9
Wood construction, demolition and furniture waste	18.9
Steam coal price (2015 average)	2.0
Natural gas price (USD 9/mBtu)	9.5
Oil price (USD 50/barrel)	8.6
LPG price (3 kg canister) (January 2016)	7.1
LPG price (5 kg canister) (January 2016)	17.9

Note: biomass supply costs include the cost of production, collection and transportation (to processor and end-user). For full methodology, see: http://www.irena.org/REMAP/IRENA_REmap_2030_Biomass_paper_2014.pdf

Source: supply cost figures based on IRENA estimates

6 REMAP OPTIONS FOR INDONESIA

Key points

- Options for additional renewable energy use ("REmap Options") have been identified to increase the share of modern renewable energy to 23.3% of TFEC and 32.3% of TPES in 2030. This includes full substitution of traditional uses of bioenergy for cooking by modern cook stoves using bioenergy.

- Of the end-use sectors, the share of modern renewables is the highest in buildings at 35% (excluding renewable electricity), compared to 5.9% in the Reference Case. With REmap, all households still relying on traditional uses of bioenergy for cooking in the Reference Case (estimated at nearly 8 million) switch to modern cook stoves that use solid biomass or ethanol. Based on an assessment of available rooftop space and realistic deployment potential, solar thermal collectors cover 30% of energy demand for water heating, while 5% of energy demand for cooling in buildings is met by solar (thermal) cooling.

- Through the assessment of the projected energy use in Indonesia's main industry sectors and the supply potential of different types of bioenergy feedstock, the REmap Options identify 216 PJ of additional bioenergy use in industry. This consists of additional potential for the use of biogas (from food waste and palm oil mill effluent), wood residues and waste. Combined with the identified potential of 70 PJ per year for solar thermal collectors to supply process heat (in the rubber, food and textile industries), the share of renewables in industry increases to 17.9%.

- Given the high increase of liquid biofuels use in transport in the Reference Case, the REmap Options in this sector focus on electric mobility. With the expected continued increase in vehicle ownership, nearly 6% of all four-wheeled vehicles and 20% of all two- and three-wheelers would be electric by 2030. Combined, they increase the share of renewable energy in transport TFEC (including renewable electricity) to 18.4% (versus 17.2% in the Reference Case).

- To assess the potential for additional renewable power in Indonesia, five regions (Java-Bali, Kalimantan, Maluku & Papua, Sulawesi & Nusa Tenggara and Sumatra) were distinguished, and for each the resource potential for different renewables and the projected demand for power in 2030 was analysed. Based on this assessment, the share of renewable energy in power generation increases to 38.3% with REmap.

- REmap Options for hydropower, geothermal, bioenergy power and wind power are modest, given their ambitious increase in the Reference Case and the geographical mismatch in resource potential and power demand. For solar PV REmap identifies potential for 47.2 GW of installed capacity by 2030, compared to 9.3 GW in the Reference Case. Especially in Java-Bali (which accounts for 70% of power demand in Indonesia) there is enough available space (both land and rooftops) and demand for power to increase the use of solar PV beyond the Reference Case.

- Annual investment needs for all renewables in the Reference Case are estimated at, on average, USD 9.4 billion between 2015 and 2030. With the REmap Options this would increase to USD 16.2 billion. The power sector accounts for USD 13.2 billion of this, nearly half of which is for solar PV.

- Implementing all REmap Options implies an average substitution cost in 2030 of USD 1.1 per GJ of final renewable energy, when compared to the annualised cost of the substituted conventional fuel. This is from a business perspective which includes taxes and subsidies on energy prices and a 12% discount rate. The substitution cost of the REmap Options in the power sector are negative (at USD -5.2 per GJ), as hydropower, geothermal power and solar PV are expected to be competitive with coal-fired power generation (which is substituted).

- From a government perspective, the average substitution cost reflects savings of USD -2 per GJ. This is due to the application of a lower discount rate (at 10%) and the exclusion of subsidies on energy prices (on residential electricity and small LPG canisters for low-income households).

- The REmap Options reduce the cost of Indonesia's energy system in 2030 by an estimated USD 1.7 billion per year (versus the Reference Case) from a government perspective. In addition, the savings from externalities related to outdoor air pollution range from USD 3 billion to USD 9 billion per year. Reduced externalities from indoor air pollution account for another USD 10.4 billion to USD 31.3 billion per year due to the substitution of traditional uses of bioenergy for cooking.

- Reduced externalities from climate change account for another USD 2.2 billion to USD 10.7 billion per year as the REmap Options would lead to a reduction of 150 Mt of CO_2 per year in 2030, a reduction of 12% compared to the Reference Case. Reductions in CO_2 emissions from power generation account for more than two-thirds of this. In sum, the REmap Options reduce system costs and achieve savings from reduced externalities of USD 17.3 billion to USD 53.4 billion per year in 2030. This represents about 0.5% to 1.7% of Indonesia's forecasted GDP for 2030.

The Reference Case analysis for Indonesia utilises an internally developed REmap tool[11] that incorporates the data, assumptions and approach, as summarised in section 4. The tool allows IRENA to enter additional potentials for renewable energy technologies ("REmap Options") in the end-use sectors of industry, buildings and transport, as well as for power generation and district heat. The process for deriving the REmap Options was as follows:

1. A Reference Case was created for 2030
2. Fuel prices were forecasted based on existing literature and IRENA estimates
3. Technology cost and performance criteria (*e.g.*, capacity factors) were estimated to reflect conditions particular to Indonesia
4. Additional renewable energy options for all end-use sectors and the power sector were analysed based on various studies and assessments.

This chapter is divided into six subsections. Section 6.1 describes the REmap Options for each of the technologies. Section 6.2 provides an overview of the combined impact of the REmap Options on total renewable energy deployed and its share in the energy mix, both in aggregate and per sector. In section 6.3 the investment needs of the REmap Options are provided, and in section 6.4 the cost supply curves of the REmap Options are provided. Finally, section 6.5 discusses the benefits in terms of reduced externalities, as well as the overall costs and benefits of the REmap Options.

6.1 Renewable energy technologies

Bioenergy

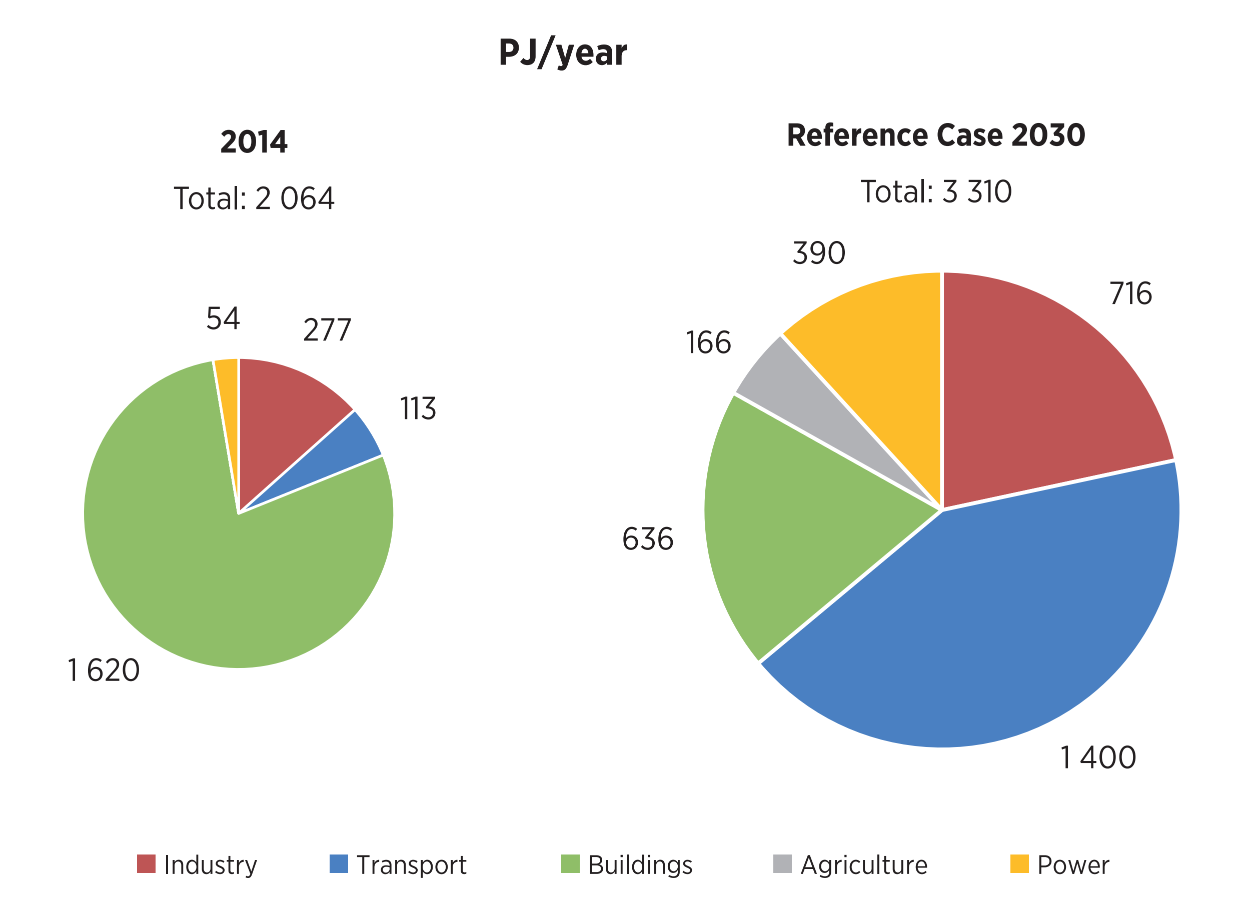
In 2014 most of the bioenergy use in Indonesia was explained by traditional cooking methods using fuelwood, accounting for 1620 PJ or nearly 80% of the total primary demand for bioenergy that year (see figure 26). Another 277 PJ was used in industry, while transport and power generation combined represented less than 10% of the total demand for bioenergy demand.

The Reference Case for 2030 shows a shift, however, in the total use and distribution of bioenergy use in Indonesia. The traditional use of bioenergy for cooking is projected to shrink, as households increasingly are adopting more modern cooking methods and fuels. Transportation is projected to increase to more than 40% of total primary energy demand in 2030, on the back of ambitious blending mandates for both ethanol and biodiesel (about 13 billion litres of biodiesel and 12 billion litres of ethanol consumed per year in 2030)[12]. Bioenergy use in industry will grow by more than 150%, particularly as a result of strong overall economic

11 More information on the tool can be found at *https://www.irena.org/remap/REmap_energy_system_models_chapter_3_2015.pdf*

12 Bioenergy use in transport is assumed to have a 50% conversion efficiency.

Figure 26: Primary bioenergy demand in Indonesia, 2014 and 2030



Source: IRENA analysis

growth and fuel use in industry, while targets for the power sector imply an eight-fold increase of bioenergy use there. Combined, modern bioenergy use (excluding traditional use of bioenergy for cooking) will increase more than six-fold, from 436 PJ in 2014 to 2 768 PJ in 2030.

The top part of table 8 shows an allocation of the demand for bioenergy in the Reference Case for various feedstock based on the supply potentials as presented in section 5.2. The bottom part of the table indicates the potential for each of the technologies and bioenergy feedstock beyond the Reference Case. The green cells highlight where more potential is, while red highlights where the resource availability poses constraints. Finally, orange indicates potentials, but at a higher cost.

The ambitious demand projections for bioenergy in the Reference Case imply constraints on the supply side, particularly for liquid biofuels. The potential for sustainable energy crops to produce first-generation liquid biofuels will meet less than 10% of the estimated demand in 2030. This implies that the remaining 90% would have to be provided by advanced biofuels, for which woody crops on surplus and marginal agricultural lands could be used as feedstock, or through the use of more degraded land and by improving yields on current plantations. Given these considerations, and the ambitious targets for liquid biofuels in the Reference Case, no additional REmap Options for biofuels are included.

Due to the constrained supply potential of agricultural processing and harvesting residues beyond the Reference Case, the REmap Options for bioenergy use in industry include only higher levels for the use of food waste, palm oil mill effluent, and wood waste and residue. In total the REmap Options include 216 PJ of additional bioenergy (final energy) consumption in industry. About 35% (or 75 PJ) of this is solid biomass

Table 8: Bioenergy supply potential and demand for bioenergy in the Reference Case for 2030, and an indication of the potential beyond the Reference Case

In 2030 (PJ)		Energy crop from non-forest land	Harvesting residue	Agro processing residue	Animal manure & post consumer household waste	Fuel wood	Wood logging and processing residue	Wood construction, demolition and furniture waste	Woody crops on surplus and marginal agricultural land
Supply potential	**Average**	**162**	**638**	**326**	**403**	**1582**	**387**	**247**	**2165**
	Low	162	422	167	137	1556	364	232	1008
	High	162	853	485	668	1608	410	263	3321
Demand (Reference Case 2030)	**Total**	**1751**	**545**	**288**	**24**	**28**	**45**	**105**	**0**
Liquid biofuels	**1751**	**1751**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ethanol	660	660	0	0	0	0	0	0	0
Biodiesel	1092	1092	0	0	0	0	0	0	0
Solid biomass in industry	**598**	**0**	**314**	**134**	**0**	**0**	**45**	**10**	**0**
Modern cookstoves based on solid biomass	**28**	**0**	**0**	**0**	**0**	**28**	**0**	**0**	**0**
Modern cookstoves based on biogas	**19**	**0**	**0**	**0**	**19**	**0**	**0**	**0**	**0**
Biogas in industry	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Power generation	**391**	**0**	**231**	**154**	**5**	**0**	**0**	**0**	**0**
Supply potential	**Average**	**162**	**638**	**326**	**403**	**1582**	**387**	**247**	**2165**
	Low	162	422	167	137	1556	364	232	1008
	High	162	853	485	668	1608	410	263	3321
Demand (Reference Case 2030)	**Total**	**1751**	**545**	**288**	**24**	**28**	**45**	**105**	**0**
Liquid biofuels	**1751**								
Ethanol	660	Re-source con-strained							Avail-able, higher cost
Biodiesel	1092								
Solid biomass in industry	**598**		Resource constrained				Available, higher cost		
Modern cookstoves based on solid biomass	**28**					Low cost			
Modern cookstoves based on biogas	**19**				Low cost, not con-strained				
Biogas in industry	**0**								
Power generation	**391**		Resource constrained				Available, higher cost		

Note: excluding traditional uses of bioenergy

Source: IRENA analysis

from wood waste used in boilers (in wood processing) and used in the form of briquettes in furnaces in glass and ceramics production, and brick making. These potentials are estimated based on the outlook for total fuel use for each industrial sectors, the share that is expected to be supplied by bioenergy in the Reference Case, and the additional potential that can be realistically captured within the 2030 time frame. Another 35% (or 73 PJ) of the REmap Options is in the form of additional use of wood residues in combined heat and power (CHP) in the paper industry, and another 30% (or 68 PJ) is from the use of biogas.

Of the REmap Options for biogas, 80% is in the form of biogas in CHP derived from palm oil mill effluent (POME). Expanding the use of POME in particular comes with the additional benefit of avoiding emissions that would occur anyway, even in the absence of combustion for heat or power generation. When biogas from effluent lagoons escapes freely into the atmosphere, not only is the potential energy content wasted, but methane with high global warming potential is released into the atmosphere. The additional biogas potential outside of POME is related to the use of food waste in CHP in the food processing industry. The additional CHP capacity relying on bioenergy is 3.9 GW, which comes in addition to the 7.1 GW of bioenergy for power generation that is included in the Reference Case for 2030.

Based on the Reference Case, about 7.8 million households (about 9% of total households) in Indonesia would still rely on traditional uses of bioenergy for cooking in 2030, or 525 PJ in final energy terms. With the REmap Options, it is assumed that these households would instead use modern cook stoves. In the Reference Case for 2030, already 2 million households use biogas for cooking (up from about 15000 today), exceeding the demand-side potential of 1 million households as explained in section 5.2. Therefore, no REmap Options for biogas cooking are included. Instead, with the REmap Options 95% of the households that would still rely on traditional uses of bioenergy in 2030 are assumed to switch to modern cook stoves using solid biomass (fuelwood). These modern cook stoves are up to four times more efficient compared with traditional cooking methods, reduce cooking times and mitigate indoor air pollution. The remaining 5% (or about 390000 households) are assumed to rely on ethanol gels for cooking, a fuel that is already used at scale in various African countries. Hence, with the REmap Options 11% (or close to 10 million households) rely on modern uses of bioenergy for cooking, while the remainder use LPG, electricity and natural gas.

Solar

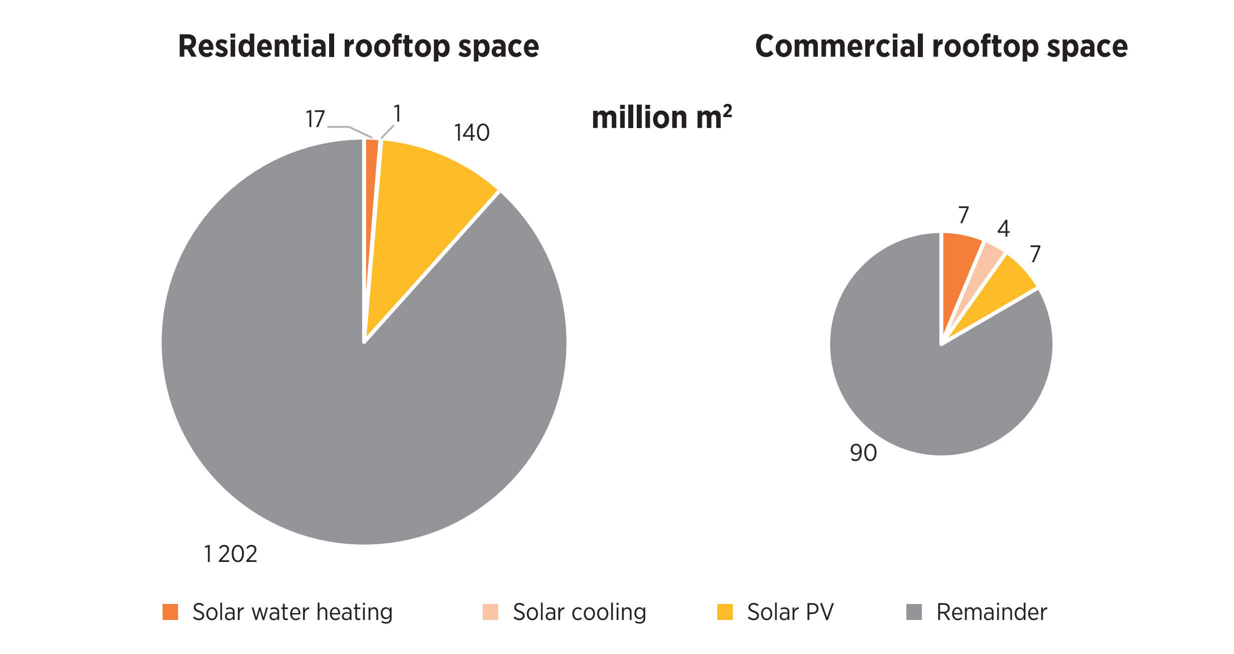
The largest potential for renewable power beyond the Reference Case has been identified for solar PV. With the Reference Case 9.3 GW would be installed by 2030; with the REmap Options this would be 47.2 GW. This number is considered feasible based on the ability for Indonesia to ramp up annual installations (to 3.1 GW per year installed on average until 2030), the amount of available space for ground-mounted and rooftop solar PV, and the ability of grids to deal with the supply of variable renewable energy.

The share of VRE generation (including solar PV, wind and marine) in total generation is assumed not to exceed 15% within any of the five regions. The latter is taken as an upper limit in estimating REmap Options for VRE in 2030. It is higher than the 10% assumption that the Indonesian Agency for the Assessment and Application of Technology (BPPT) currently uses in its energy modelling in Indonesia and the 10% daytime peak load based on PLN requirements to project developers. However, with planned grid developments, and based on the experience of other countries, it was assumed that 15% should be feasible by 2030. In fact, grids in many countries are already dealing with higher shares, and the 15% is not a binding technical boundary. Instead, given the limited availability of data on actual grid conditions, the 15% is taken as a conservative upper limit.

Most of the additional solar PV installations are assumed to be in Java-Bali (to reach 33.4 GW by 2030, about 85% of the total theoretical potential for solar PV there), due to the resource availability close to demand centres and the modest share of VRE in power generation in the Reference Case at 4%. With the REmap Options, Java-Bali will have an 11% VRE share. Based on the assessment of available rooftop space in 2030, less than one-third of the installed solar PV capacity is estimated to be deployed in the form of rooftop solar PV. Commercial rooftop space in particular is more limited (see figure 27). Hence, 95% of rooftop solar PV is assumed to be installed on residential rooftops. Based on the projected growth in rooftop space in Indonesia, this implies that 10% of residential rooftops and 7% of commercial rooftops will be covered by solar PV in 2030.

The potential for direct use of solar technologies in residential and commercial buildings in Indonesia

Figure 27: Use of residential and commercial rooftop space for solar technologies in Indonesia in 2030 with the REmap Options



Source: IRENA analysis

includes applications for solar water heating and solar cooling. Water heating demand is projected to increase significantly by 2030, from an estimated 127 PJ in 2014 to 313 PJ in 2030. This is due to increasing energy demand in cities and to the above-average growth in energy use in commercial buildings (responsible for 25% of water heating demand in 2030). The REmap Options assume that 40% of water heating could be met by solar collectors in Indonesia by 2030, equal to 109 PJ of final energy consumption. This is in line with the business-as-usual outlook for China, which currently accounts for more than half of all solar water heating globally. Although the market for solar water collectors in Indonesia is not as mature as it is China, the solar resource in Indonesia is higher on average, making solar water collectors an interesting option for substituting petroleum products for water heating. As shown in figure 27, the required rooftop space amounts to 17.5 million m² for residential solar water collectors (about 1-1.5% of total residential rooftop space in 2030) and 6.8 million m² of commercial rooftops (about 6-7% of total commercial rooftop space in 2030).

Demand for cooling in buildings is projected to increase from 214 PJ in 2014 to 826 PJ in 2030, to represent about 28% of total energy demand in buildings. The implied annual increase of nearly 8% per year is in line with the rapid expected growth in air conditioning sales, which are estimated to increase 10% per year between 2013 and 2018 (BusinessWire, 2014). Just over 70% of cooling demand is in commercial buildings, which account for nearly 80% of the increase in total cooling demand between now and 2030. Of the increase in energy demand for cooling, absorption chillers using hot water from solar collectors are assumed to cover 5%. Assuming that the systems provide cooling for about three hours per day, this equates to 22 PJ in final energy terms in 2030. The total space required for these installations is estimated at 5 million m², less than 1% of available rooftop space. Given the already significant increase in rooftop solar PV (for electricity generation), no REmap Options for stand-alone solar PV cooling are included.

Finally, in industry a 20% penetration rate for solar thermal is considered feasible by 2030 for the natural rubber, food and textile industries, which rely on low (150 °C) and medium (150-400 °C) heat. This results in 70 PJ of substituted heat (from petroleum products) in the same year.

Hydropower

Hydropower capacity will be significantly expanded in the Reference Case (up to 28.6 GW by 2030, from 5.2 GW in 2014). Most of the hydropower resource potential is found outside Java-Bali where lower demand for electricity is a constraint to increasing installations. Hence, the REmap Options only include the additional exploitation of small hydropower of 1.1 GW, mainly on Sumatra, where 35% of the resource potential is assumed to be used by 2030 (compared to 21% in the Reference Case).

The large hydropower resource on Java-Bali is already assumed to be exploited fully by 2030. This, along with the fact that for the other regions there are demand constraints as well as sustainability concerns associated with exploiting the resource (*e.g.*, deforestation, displacement of a high number of people), explain why no REmap Options for large hydropower are included. Based on the Reference Case 19.3 GW already is assumed to be added between now and 2030, exceeding the estimated 10 GW of economically feasible hydropower potential as explained in section 5.1. At an average expected project size of 150 MW (based on projects that were under construction or in feasibility study/planning phases in 2015), this implies that nearly 130 projects are required to achieve this. Based on existing assessments of potential sites, these projects are likely to be distributed across a large number of rivers and reservoirs on the different islands of Indonesia (MEMR, PLN and JICA, 2011).

Geothermal

In the Reference Case, geothermal capacity is set to grow quickly, from 1.4 GW in 2014 to 8.9 GW in 2030. Beyond this ambitious projection, the REmap Options include 1.7 GW of additional geothermal power, to reach 10.6 GW of installed capacity in 2030. Java-Bali accounts for 800 MW of the REmap Options; Sumatra accounts for the remainder. As a result, 60% of the resource potential in Java-Bali will have been exploited by 2030, and 30% of the potential in Sumatra. Outside of these two regions, demand constraints and resource accessibility are assumed to limit a further increase of geothermal installations beyond the Reference Case.

Wind

With the REmap Options the installed capacity of wind power (all onshore) will reach 4.1 GW in 2030 – 45% of the identified potential for wind power in Indonesia. The addition of 1.5 GW beyond the Reference Case is assumed to be on Java-Bali, where the best wind resources have been identified and where the grid is most likely to be able to absorb the additional VRE. The additional wind power capacity can be considered conservative given the maturity and cost competitiveness of the technology. However, it is based on currently availability resource assessments and takes into account power demand limitations. Additional resource mapping, which is ongoing, might highlight additional potential in new locations.

Electric mobility

For electric mobility, significant potential beyond the Reference Case is identified. The REmap Options for electric vehicles and electric two- and three-wheelers amount to 13.1 TWh (or 47.3 PJ) of final energy consumption in 2030. Passenger and commercial vehicles (four-wheelers) account for nearly two-thirds of the total potential. Based on the expected sales of cars until 2030 and on a gradually increasing market share for electric vehicles, it is estimated that about 6% of the total vehicle stock in Indonesia would be electric in 2030. In the same year, electric vehicles would have a 25% market share in the passenger cars segment and a 10% market share in commercial vehicle sales.

For electric motorcycles and scooters the feasible penetration is higher by 2030; 20% of all two- and three-wheelers could be electric by 2030 based on a roadmap gradually reaching a 75% market share in total two- and three-wheelers sales in the same year. This totals about 42.5 million electric two- and three-wheelers on the road by 2030 and average sales of about 3 million of these between now and 2030. The case of China shows that this is feasible: about 200 million electric two- and three-wheelers were in use there in 2012, and sales are expected to exceed 10 million per year on average up to 2030 (IRENA, 2014b).

Electric vehicles, scooters and motorcycles also can play an important role in providing energy storage. Most of the time they will not be used, and during this time their batteries have the potential to charge and discharge to balance the demand and variable supply of power (*e.g.*, from solar PV). Based on REmap, the storage provided in this way amounts to 93.3 GWh per year. Total electric storage stands at 105.1 GWh per year; the difference is explained by 11.8 GWh per year of electric storage provided by batteries that are installed with rooftop solar PV. Although overall the electric storage capacity remains modest (105.1 GWh per year represents about 0.1% of total variable power generation with REmap), in and around large cities where most of the electric mobility can be expected this could be a useful flexibility option.

6.2 Summary of results

With the REmap Options, the share of (modern) renewable energy in TPES increases to 32.3%, up from 25.3% in the Reference Case and around 9% today. The renewable energy share in TFEC increases to 23.3% with the REmap Options (see table 9). Among the end-use sectors, buildings demonstrate the highest potential for renewable energy penetration, at 37.1% (including the contribution of renewable electricity). Industry is the second highest sector, where the REmap Options take the renewable energy share to 20.6% of the sector's TFEC in 2030. In absolute terms, industry has the highest potential for renewables and represents nearly 40% of total renewable energy use. With the addition of the REmap Options, 881 PJ of heat is supplied by bioenergy and solar thermal collectors, while another 294 PJ is used in the form of electricity supplied by renewable power generation. In transport, the blending mandates and the additional electric vehicles with the REmap Options result in an 18.4% renewable share in the sector's TFEC for 2030. The contribution from renewable electricity remains modest, at 24 PJ. In power generation the REmap Options imply an additional 92 TWh of additional power generated by renewables, increasing the total renewable energy share to 38.3%, from 28.6% in the Reference Case.

Bioenergy will continue to be the dominant source of renewable energy in Indonesia with REmap, accounting for more than half of total renewable energy use in the country (see figure 28). The total use of bioenergy equates to just over 1.8 EJ, or 15% of TFEC. This represents an increase of 1.5 EJ from 2014, when modern uses of bioenergy accounted for less than 5% of TFEC. Hydropower is next, and contributes 308 PJ to TFEC in 2030, up from 47 PJ in 2014.

The largest additions with the REmap Options are for solar energy (including both PV and thermal) (see figure 29). In the Reference Case, solar power supplies about 2% of total renewable energy use; with the REmap Options this would increase to 15%. Geothermal power increases nearly seven-fold from 2014, to about 210 PJ or 9% of total renewable energy use in 2030. The contributions of marine and wind energy remain limited, with their combined share in total renewable energy use at below 3%.

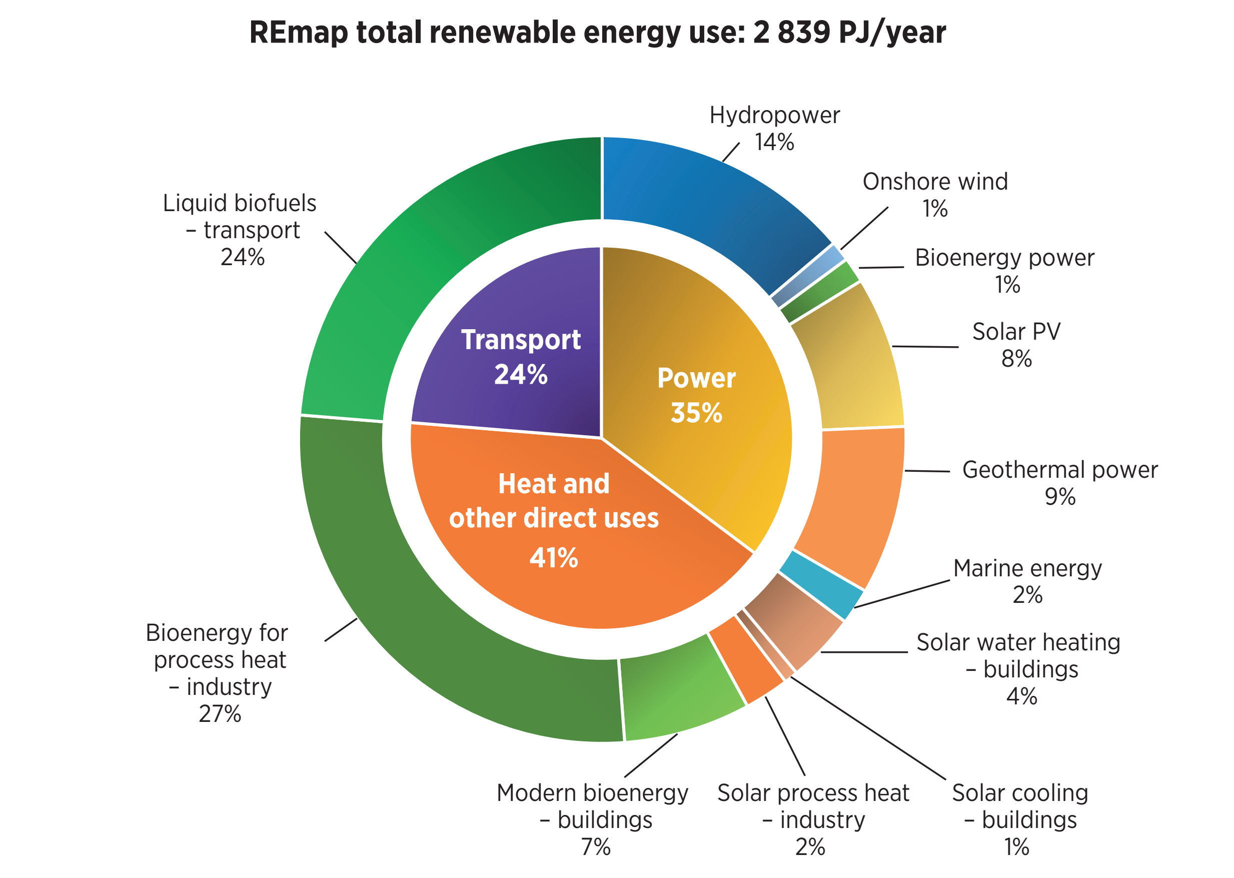
Figure 30 shows the implications for the power sector in terms of annual installations for renewable energy technologies. It is obvious that compared to recent market trends, in both the Reference Case as well as with the REmap Options deployment across renewable technologies would need to be accelerated. With the REmap Options, the largest market will be for solar

Table 9: Breakdown of renewable energy share by sector

Share of renewable energy in final energy consumption / power generation		2014	2030 Reference Case	2030 REmap	RE use REmap (PJ/year)
Industry	Heat only	11.5%	13.3%	17.9%	881
	Including renewable electricity	11.6%	15.4%	20.6%	1 175
Buildings	Heat only	0.0%	5.9%	35.0%	331
	Including renewable electricity	2.5%	18.2%	37.1%	940
Transport	Fuels only	2.8%	17.1%	18.0%	700
	Including renewable electricity	2.8%	17.2%	18.4%	724
Power		12.4%	28.6%	38.3%	1 180
Share in total final energy consumption		**5.8%**	**16.6%**	**23.3%**	**2 839**
Share in total primary energy supply		**8.8%**	**25.3%**	**32.3%**	**6 713**

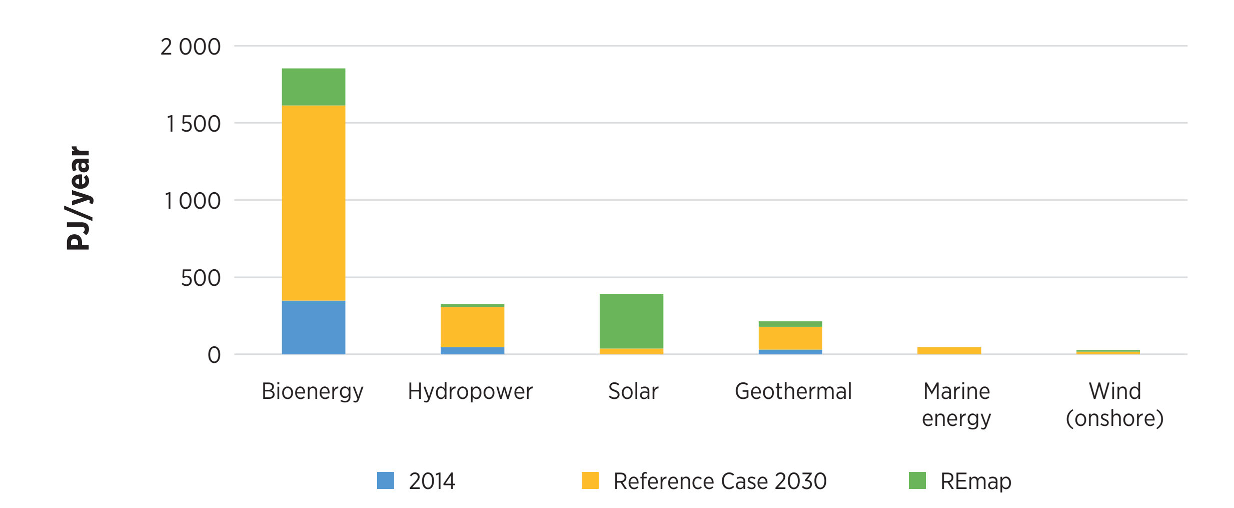
Source: IRENA analysis

Figure 28: Breakdown of renewable energy in total final energy consumption with REmap across sectors and technologies, 2030



Source: IRENA analysis

Figure 29: Increases in modern renewable energy consumption in total final energy consumption by renewable energy resource



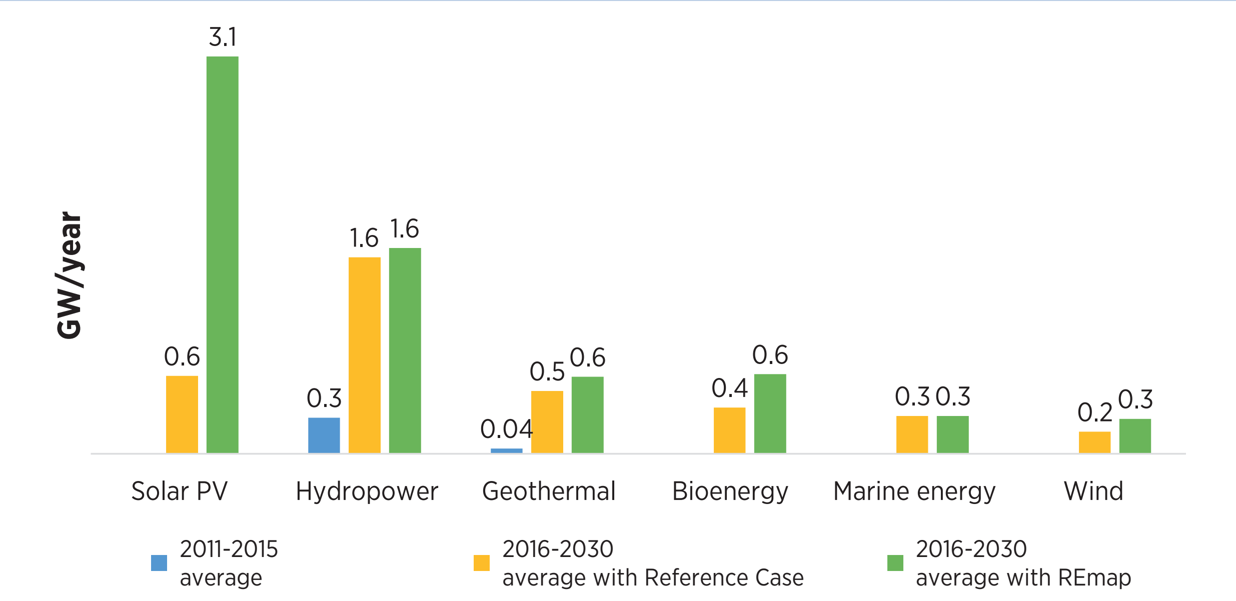
Note: excludes traditional uses of bioenergy

Source: IRENA analysis

Table 10: Indonesia REmap analysis overview

	Units	2014	Reference Case	REmap
Power				
Installed Capacity				
Hydropower	**GW**	**5.3**	**29.6**	**30.7**
Large hydropower (>10 MW)	GW	5.1	24.3	24.3
Small hydropower (<10 MW)	GW	0.2	4.3	5.4
Pumped hydropower	GW	0.0	1.0	1.0
Wind (onshore)	**GW**	**0.0**	**2.6**	**4.2**
Solar PV	**GW**	**0.0**	**9.3**	**47.2**
Utility scale (on-grid)	GW	0.0	2.4	30.4
Rooftop (on-grid)	GW	0.0	4.8	14.7
Off-grid	GW	0.0	2.1	2.1
Bioenergy	**GW**	**1.7**	**7.2**	**11.2**
Geothermal	**GW**	**1.4**	**8.9**	**10.6**
Flash steam, dry steam	GW	1.4	8.5	10.0
Binary	GW	0.0	0.4	0.5
Marine energy (tidal)	**GW**	**0.0**	**4.5**	**4.5**
Total installed power capacity	**GW**	**57.6**	**199.3**	**225.2**
Generation				
Hydropower	**TWh**	**15.2**	**106.9**	**113.2**
Wind (onshore)	**TWh**	**0.0**	**5.7**	**9.1**
Solar PV	**TWh**	**0.0**	**13.0**	**66.2**
Bioenergy	**TWh**	**4.6**	**32.5**	**49.8**
Geothermal	**TWh**	**10.0**	**62.1**	**73.8**
Marine energy (tidal)	**TWh**	**0.0**	**15.8**	**15.8**
Total power generation	**TWh**	**240.3**	**826.2**	**837.6**
Share of renewable energy in power generation	**%**	**12%**	**29%**	**38%**
Battery storage (incl. EVs and 2/3 wheelers)	**GWh**	**0.0**	**1.9**	**105.1**
Transport				
Electric vehicles	**million vehicles**	**0.0**	**0.0**	**3.2**
Passenger vehicles	million vehicles	0.0	0.0	2.7
Commercial vehicles	million vehicles	0.0	0.0	0.4
Electric 2/3 wheelers	**million vehicles**	**0.0**	**0.0**	**42.5**
Bioliquids	**billion liters**	**1.8**	**25.8**	**25.8**
Conventional biogasoline	billion liters	0.0	12.0	12.0
Advanced biogasoline	billion liters	0.0	0.0	0.0
Conventional biodiesel	billion liters	1.8	13.1	13.1
Advanced biodiesel (incl. bio jet kerosene, drop-in)	billion liters	0.0	0.0	0.0
Industry				
Bioenergy heat (incl. CHP)	**PJ/yr**	**277**	**657**	**811**
Agricultural residues	PJ/yr	243	448	448
Forestry products	PJ/yr	33	150	236
Biogas	PJ/yr	0.0	0.0	68
Liquid biofuels	PJ/yr	0.0	59.4	59.4
Solar thermal – flat plate, evacuated tube	**million m^2**	**0.0**	**0.0**	**15.6**
Buildings				
Bioenergy – traditional cooking	**PJ/yr**	**1 612**	**525**	**0**
Bioenergy – advanced cooking	**PJ/yr**	**0.0**	**19**	**139**
Traditional uses of bioenergy for cooking	**million households**	**24.0**	**7.8**	**0.0**
Modern bioenergy based cookstoves	**million households**	**0.02**	**2.0**	**9.8**
Solid biomass	million households	0.0	0.0	7.4
Biogas	million households	0.02	2.0	2.0
Ethanol gel	million households	0.0	0.0	0.4
Solar thermal – water heating	**million m^2**	**0.0**	**0.0**	**24.3**
Solar thermal – cooling	**million m^2**	**0.0**	**0.0**	**4.9**

Figure 30: Annual installations of renewable power, 2011-2015, in the Reference Case for 2030 and with REmap



Source: IRENA analysis

PV at 3.1 GW per year from 2016 to 2030, to reach 47 GW of installed capacity by 2030. For the other technologies, the Reference Case presents an ambitious outlook compared to historical deployment levels, and the REmap Options show a more limited increase. For hydropower, 1.6 GW per year would need to be installed, up from about 300 MW per year on average in 2011-2015. It should be noted that hydropower has been the only renewable technology for which a significant increase in capacity was witnessed in recent years. For geothermal power the REmap Options imply annual installations of 0.6 GW for installed capacity to reach 10.6 GW by 2030. Bioenergy, marine energy and wind power together would account for another 1 GW annual market.

6.3 Investment needs

To achieve the renewable targets as included in the Reference Case, the required investment amounts to USD 9.4 billion per year in 2015-2030 (see table 11). Of the total, the power sector accounts for almost 85% of the investment required. Hydropower represents the largest amount at USD 2.5 billion per year, nearly one-third of overall required investment in renewable power capacity. Of the end-use sectors, required investment in the transport sector is the highest at USD 1.0 billion per year, the capital expenditure associated with expanding biofuel production capacity. Additional investments in industry comprise capital expenditures to achieve the higher levels of bioenergy use in the sector.

With the REmap Options, the required investment increases to USD 16.2 billion per year for the years 2015-2030. While no additional investments are required in transport (electric vehicles and infrastructure are not included, since they do not represent direct capital expenditure for renewable energy), investment needs in industry more than double. The increase is explained due to identified potential for more bioenergy and solar thermal installations. In buildings, investment needs increase to USD 0.8 billion per year, of which 98% is explained by the identified potential for solar thermal water heating and cooling applications. The remaining 2%, or about USD 222 million up to 2030, would be required to pay for modern cook stoves for the 8 million households that would still rely on traditional uses of bioenergy for cooking in 2030 with the Reference Case. Clearly, the capital intensity of modernising cooking across Indonesia is very low compared to achieving higher levels of renewable energy use in other sectors. Investments in renewable power would need to increase to USD 13.2 billion per year on average in 2015-2030 to

Table 11: Average annual investment needs in renewable capacity in 2015-2030

	Reference Case	REmap
	USD bn/year	USD bn/year
By sector	**9.4**	**16.2**
Buildings	0.0	0.8
Industry	0.5	1.2
Transport	1.0	1.0
Power	7.9	13.2
Power sector	**7.9**	**13.2**
Hydropower	**2.5**	**2.7**
Large hydropower (>10 MW)	1.8	1.8
Small hydropower (<10 MW)	0.7	0.9
Geothermal	**1.5**	**1.8**
Solar PV	**2.0**	**6.3**
Utility scale (on-grid)	0.2	3.0
Rooftop (on-grid)	0.7	2.3
Off-grid	1.1	1.1
Wind	**0.3**	**0.4**
Marine energy	**1.2**	**1.2**
Bioenergy	**0.4**	**0.7**

Source: IRENA analysis

achieve the REmap Options. Solar PV shows the largest increase, up to USD 6.3 billion per year, explained by the high level of additional potential that has been identified for both utility-scale and rooftop solar PV.

6.4 Cost of REmap Options

Table 12 provides an overview of substitution costs by sector for 2030 based on a business and government perspective. In the business perspective, a 12% discount rate for Indonesia is assumed and taxes and subsidies in energy prices are included. Given the government's recent efforts to phase out fossil fuel subsidies, as explained in section 3.3, only subsidies on residential electricity prices and LPG use in households are included for 2030. The government perspective excludes taxes and subsidies in energy prices and assumes a standardised 10% discount rate. In both the business and government perspectives, the REmap Options in the power sector are cost-effective. Across all sectors, the average substitution costs for the REmap Options are USD 1.1 per GJ and USD -2 per GJ, respectively, for the business and government perspectives. The difference is due mainly to fossil fuel subsidies: without these the REmap Options are indeed viable (as shown by the negative substitution cost in the government perspective).

Table 12: Average substitution cost of REmap Options by sector, 2030

	Business perspective	Government perspective
	USD/GJ	USD/GJ
Industry	7.7	7.0
Buildings	2.9	-6.4
Transport	3.2	10.3
Power	-5.2	-6.3
Average of all sectors	**1.1**	**-2.0**

Source: IRENA analysis

The cost-effectiveness of the REmap Options in power generation is explained mainly by the cost competiveness of hydropower and geothermal power, as well as of utility-scale solar PV (see table 13). While geothermal and (small) hydropower already present low-cost opportunities in Indonesia, global cost reductions in solar PV are expected to continue, and lower specific costs for Indonesia are anticipated due to the scale-up of the solar market there. At the same time, coal prices (coal is the fuel which the renewable power technologies are assumed to substitute) are expected to increase to about USD 100 per tonne by 2030 – from about USD 70 per tonne in October 2016 – in line with the Outlook Energi Indonesia 2015 of BPPT (BPPT, 2015). This further improves the viability of renewable power generation in Indonesia.

Of the end-use sectors, the REmap Options in industry and transport have positive substitution costs. However, solar thermal in industry and increased use of CHP provide viable solutions to further increase the share of renewables in industry. While the substitution cost for transport options (in electric mobility) are generally positive, it is important to realise that these calculations do not yet account for reductions in externalities. Taking into account the high associated cost of air pollution in many of Indonesia's cities greatly improves their viability. In buildings, the displacement of subsidised LPG by solar thermal for water heating and modern cook stoves using solid biomass provide a particularly good business case.

Figure 31 and figure 32 rank the costs of each REmap Option and show their contributions to the increase in the share of renewable energy in the business and government perspective, respectively. The dark green bars show that in the Reference Case the share of modern renewables (excluding traditional uses of

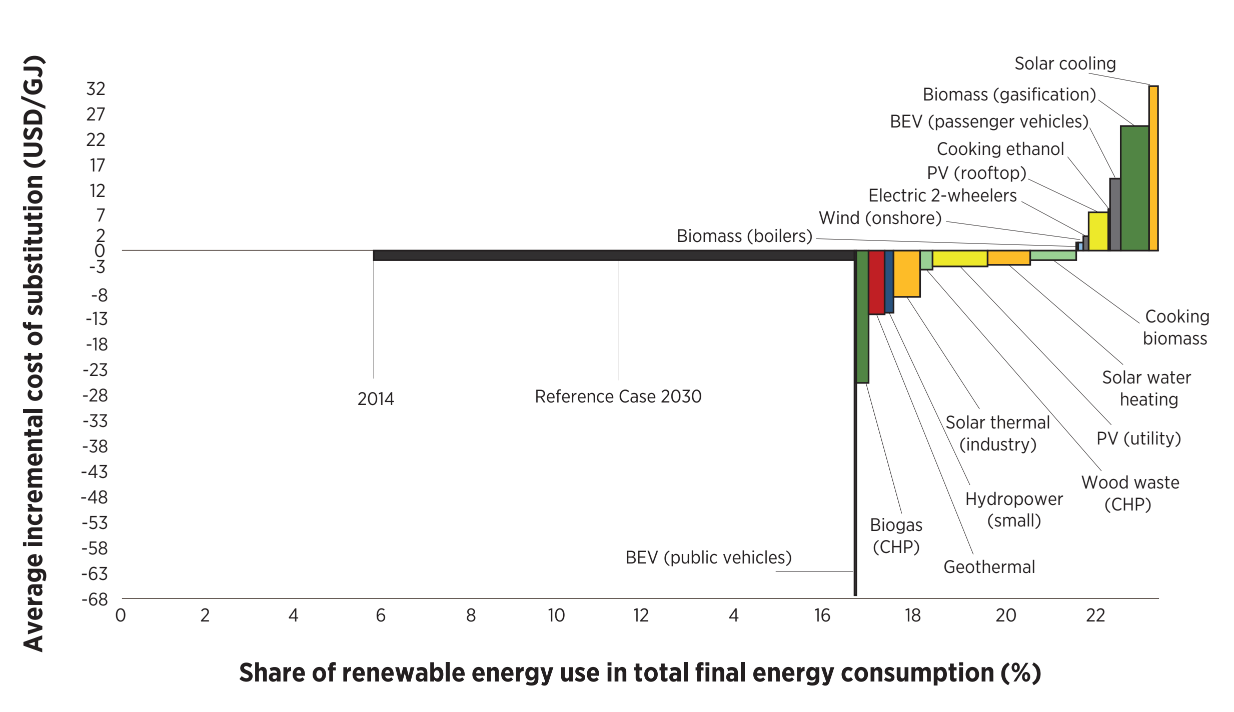
Table 13: Substitution cost and potentials of REmap Options by technology in 2030

	REmap Option	Business perspective	Government perspective
	PJ/year	USD/GJ	USD/GJ
Power			
Geothermal	42.1	-12.7	-12.8
Hydro (small)	22.5	-12.1	-12.6
Solar PV (utility)	141.3	-3.0	-4.8
Wind onshore	12.2	1.6	0.0
Solar PV (rooftop)	50.0	7.6	4.4
Industry			
Bioenergy CHP (biogas)	30.0	-26.1	-24.5
Solar thermal	70.1	-9.0	-10.1
Bioenergy CHP (wood waste)	32.2	-3.7	-2.1
Biomass boilers	4.4	1.4	1.3
Biomass gasification	71.1	24.5	23.5
Transport			
Battery-electric two-wheeler (passenger road)	14.9	2.8	-3.2
Battery-electric (passenger road vehicles)	28.2	14.2	16.3
Battery-electric (public road vehicles)	4.3	-67.5	17.4
Buildings			
Water heating: solar (thermosiphon)	109.3	-3.0	-16.2
Cooking biomass (solid)	117.0	-1.7	-1.7
Cooking ethanol	3.7	8.0	8.0
Space cooling: solar	21.9	32.3	42.6

Note: large hydropower and marine energy are not included in this table as they are not included as REmap Options (so, they no additional potential beyond the Reference Case)

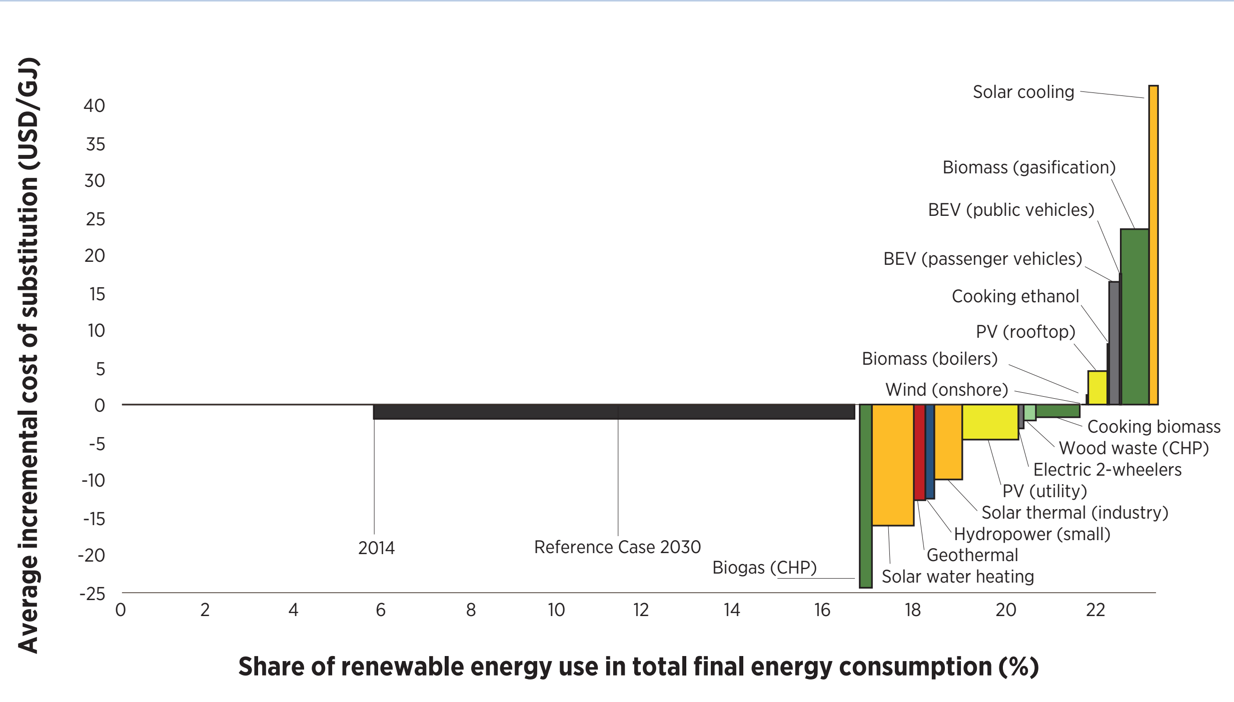
Source: IRENA analysis

Figure 31: Renewable energy cost-supply curve by renewable energy resource in 2030, from the business perspective



Source: IRENA analysis

Figure 32: Renewable energy cost-supply curve by renewable energy resource in 2030, from the government perspective



Source: IRENA analysis

bioenergy) increases to 16.6%, from 5.8% in 2014. With the REmap Options this would further increase to 23.3%, whereby the substitution costs range from USD -67.5 per GJ to USD 32.2 per GJ in the business perspective, and from USD -24.5 per GJ to USD 42.6 per GJ in the government perspective. Considering merely the cost-effective REmap Options would take the share of renewables to 21% (the end of the light-green bars). However, these calculations do not include the associated benefits of reduced air pollution and CO_2 emissions, which are detailed in the next section. In the government perspective, this analysis shows, additional use of biogas, solar water heating and geothermal power are among the most cost-effective options to increase the share of renewable energy beyond the Reference Case.

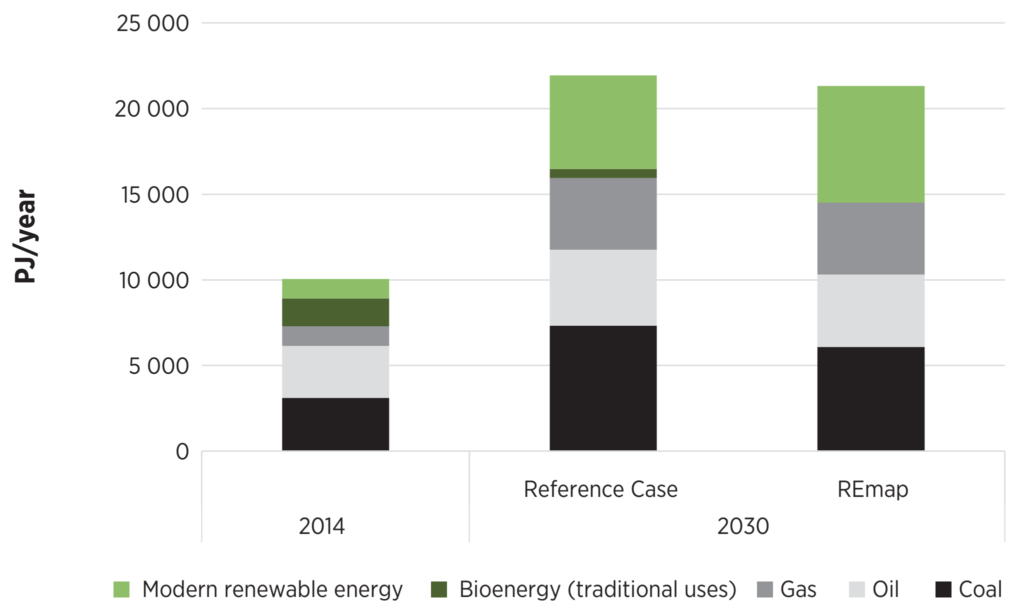
6.5 Benefits of REmap Options

As shown in figure 33, the primary energy supply of fossil fuels is expected to more than double between 2014 and 2030 in the Reference Case. Coal experiences the highest increase of about 4.2 EJ – from 3.1 EJ in 2014 to 7.3 EJ in 2030 – due to its greater use in power generation and industry. Natural gas use increases the most in relative terms, rising 160% from 1.1 EJ in 2014 to 4.2 EJ in 2030. Oil use also increases due to fast growth in transport energy demand, although the increase is somewhat more limited (+47%) due to oil's lower share in meeting energy demand in power generation and industry.

With the REmap Options, fossil fuel demand will be cut by 10% compared with the Reference Case, based on a 17% reduction in coal use and a 9% reduction in oil use. At the same time, traditional uses of bioenergy will be phased out completely, due to the uptake of modern cook stoves using bioenergy. Modern renewable energy will represent 32% of TPES, compared to 25% in the Reference Case.

The reduction of fossil fuel use cuts projected CO_2 emissions. Based on a bottom-up estimate of the sectors covered in this analysis, CO_2 emissions from fossil fuel combustion for energy services in 2014 accounted for 584 Mt CO_2/year (or about 2.3 tonnes per capita), of which power generation contributed nearly 40% (see table 14). According to the Reference Case, energy-related CO_2 emissions increase to 1253 Mt CO_2/year by 2030, more than a doubling from 2014. The share of power generation increases to nearly half of the total. With the REmap Options, 150 Mt CO_2/year are avoided, representing a 12% reduction from the Reference Case.

Figure 33: Total primary energy supply in Indonesia, 2014-2030



Source: IRENA analysis

In its NDC, Indonesia pledges to reduce greenhouse gas emissions 29% by 2030 compared to a business-as-usual scenario that results in projected emissions of 2869 Mt CO_2-eq in the same year (UNFCCC, 2016). Of this, 1669 Mt CO_2-eq/year are energy-related emissions. To compare this to IRENA's Reference Case this should be reduced by about 15%, to exclude non-CO_2 greenhouse gas emissions, non-energy use and sectors not included in IRENA's estimates. The resulting comparable level of energy-related CO_2 emissions of 1400 Mt CO_2-eq/year is higher than the 1253 Mt CO_2/year as estimated for IRENA's Reference Case. The difference is explained mainly by the assumption in the NDC's business-as-usual scenario that coal is the main energy source for power plants and that there is no implementation of liquid biofuel blending mandates in the transport sector. In IRENA's Reference Case, Indonesia's renewable energy target for 23% in TPES by 2025 is already included.

With the Reference Case and including the REmap Options, the energy-related CO_2 emissions are likely to be below those targeted by Indonesia in the unconditional and conditional mitigation scenarios. The reduction in the unconditional mitigation scenario for the energy sector in Indonesia's NDC is 314 Mt CO_2-eq/year by 2030. The emission reductions of the REmap Options (150 Mt CO_2/year) thus account for nearly half of this. The conditional target of Indonesia to reduce greenhouse gas emissions 41% by 2030 versus the business-as-usual scenario comes with 398 Mt CO_2-eq/year by 2030, of which the REmap Options would account for nearly 40%.

Reducing emissions through further energy efficiency improvements (see box 2) and in other sectors, particularly from land use, land-use change and forestry (LULUCF), will also be crucial. The business-as-usual outlook in Indonesia's NDC does not include any energy efficiency improvements. Furthermore, in Indonesia's business-as-usual outlook greenhouse gas emissions from forestry (including from peat fires) are 714 Mt CO_2-eq/year in 2030. The reduction in the unconditional mitigation scenario for emissions from forestry is 497 Mt CO_2-eq/year, higher than the ambition for reductions in the energy sector.

Table 15 outlines several broad financial indicators associated with implementation of the REmap Options. First, costs of the energy system would be reduced by USD 1.7 billion per year overall compared to the Reference Case. The power sector accounts for the largest savings (of about USD 2.1 billion per year) followed by cost reductions in residential and commercial buildings of USD 1.7 billion per year. While cost levels in industry and transport would be higher, it is important to put these into perspective given the high savings from reduced externalities. With the REmap Options about USD 16 billion to USD 52 billion per year would be saved from reduced externalities.

A majority of this, USD 10.4 billion to USD 31.3 billion per year, is related to the reduction of indoor air pollution caused by the traditional use of bioenergy for cooking. Given the relatively low level of investment required for implementation (as mentioned, about USD 220 million for the required number of cook stoves), this presents a high-impact opportunity when externalities are accounted for.

Outdoor air pollution savings account for another USD 3 billion to USD 9.7 billion per year. About USD 0.9 billion to USD 3.7 billion per year of this is related to reduced air pollution due to electric mobility.

Table 14: Development of energy-related carbon dioxide emissions (excluding non-carbon dioxide greenhouse gases), 2014-2030

	2014	2030		Avoided with REmap Options
Mt/year		**Reference Case**	**REmap**	
Power generation	226	605	497	107
Industry	176	336	320	17
Transport	153	256	240	16
Buildings	29	56	46	10
Total	**584**	**1253**	**1103**	**150**

Note: excluding non-CO2 greenhouse gas emissions, non-energy use and other sectors

Source: IRENA analysis

Box 2: Synergies between renewable energy and energy efficiency

Energy intensity in Indonesia has been declining in recent years. Between 1990 and 2010 the decline in energy intensity (defined as primary energy use in MJ / GDP PPP in USD) was -0.9% per year; between 2010 and 2012 it accelerated further to -5.1% per year (IEA and World Bank, 2015). Until 2025, Indonesia targets an annual change of -1% in energy intensity, as per the National Energy Conservation Master Plan (which is currently being updated).

In the Reference Case, energy intensity will further decrease between 2014 and 2030 by -2.5% per year. While primary energy supply will continue to increase (by 5% per year), the projected growth in real GDP of 7.7% per year (as per the Outlook Energi Indonesia 2014) implies that there is a significant reduction in energy used per unit of GDP. With the REmap Options, energy intensity will change by -2.9% per year over the same period, due to the lower primary energy supply as a result of additional renewable energy in the mix. In general renewables come with a higher conversion efficiency compared with their conventional counterparts and thus contribute to Indonesia's targets for reducing energy intensity as well.

However, more potential for improving energy efficiency exists in the long run. In the Outlook Energi Indonesia 2015, a high-efficiency scenario (which also includes significantly more renewables) indicates the potential for the change in energy intensity to be -3.1% per year until 2030 (MEMR, 2016h). These additional energy efficiency improvements and conservation efforts can further contribute to lowering CO_2 emissions and putting Indonesia on its NDC path. Accelerating the deployment of renewable energy thus should be complemented by driving energy efficiency improvements.

Given that the additional costs to the transport energy cost are USD 0.9 billion per year, this illustrates the viability of the REmap Options for electric mobility. Finally, reduced CO_2 emissions imply additional savings of USD 2.4 billion to USD 11.2 billion per year. This is based on a value of CO_2 of between USD 17 and USD 80 per tonne (IRENA, 2016a).

To implement the REmap Options, the incremental government support needs are estimated at USD 3.7 billion per year in 2030. This is a substantial amount, but it is small in comparison to the overall USD 17.3 to USD 53.4 billion per year in reduced energy system costs and externalities that come with the REmap Options. This represents about 0.5% to 1.7% of Indonesia's forecasted GDP for 2030, which is estimated to reach USD 3.7 trillion by that year (IHS, 2016). The additional jobs created in the renewable energy sector as well as the positive externalities related to capacity building and technology transfer come in addition to these benefits.

Table 15: Financial indicators for renewable energy use in Indonesia, from the government perspective

Annual energy system costs and savings in 2030 (REmap vs. Reference Case)	(USD billion per year in 2030)
System costs from REmap Options	**-1.7**
Industry	1.6
Buildings	-1.7
Transport	0.5
Power	-2.1
Savings from reduced externalities	**15.6 to 51.6**
Reduced externalities from outdoor air pollution	3 to 9.7
Reduced externalities from indoor air pollution (traditional biomass)	10.4 to 31.3
Reduced externalities from climate change	2.2 to 10.7
System costs from REmap Options and reduced externalities	**-17.3 to -53.4**
Incremental government support needs (without externalities)	**3.7**

Source: IRENA analysis

7 BARRIERS AND OPPORTUNITIES FOR RENEWABLE ENERGY UPTAKE

7.1 Barriers and opportunities in the power sector

By 2030, power generation capacity in Indonesia is set to increase to 199.3 GW, up from 57.6 GW at the end of 2014. Renewable power capacity in the Reference Case will be 61 GW, compared to just 8.4 GW today. With the REmap Options, the renewable energy power capacity would increase further to 107 GW by 2030. Several barriers are currently holding back growth for renewable power in Indonesia, while other challenges are anticipated to arise in implementing the REmap Options. These barriers, as well as opportunities to mitigate them, are grouped into key topics of: grid integration, cost recovery for PLN, off-grid deployment, project financing, and land acquisition and community involvement. These are discussed below, after which technology-specific barriers and opportunities are discussed for solar PV, hydropower, geothermal power, bioenergy power, marine energy and wind power.

Grid integration

Indonesia's electrical grid system is fragmented, given the archipelagic nature of the country. More than 600 isolated grid systems are in operation, not including the smaller grids supplying small cities and villages. Many of the large cities located on the same island still operate on independent and isolated grids. The relatively small size of the grids, even when they serve cities with significant population, limits how much VRE (solar, wind, marine energy) can be installed. Today, a limit of 10% VRE penetration from the daytime peak load is imposed by PLN to ensure grid stability. With this requirement, the potential for VRE is limited, both in terms of plant size and in terms of the number of suitable locations.

Because of the number of isolated grid systems as well as the grid sizes, it is difficult to generalise the grid condition and to create a policy or a plan that works well across all regions. The largest grid system at present is the Java-Bali system, with about 40 GW of installed capacity. In the isolated grid systems such as West Kalimantan, Central Kalimantan and many others, grid sizes are much smaller, and these also often include much older power plants. In addition, generation forecasting or requirements for centralised monitoring and access to power plants are limited at the moment. This means that it will be difficult to increase the penetration of variable renewables in the grid in the short term.

Another bottleneck is PLN's distribution system, which is unlikely to be able to accommodate high amounts of distributed solar PV power without additional investments. For rooftop PV systems this could pose challenges, as connecting to the transmission substation is unusual at present and might come with significant additional cost. At the same time, the fact that solar power is available when the demand for air conditioning is high might reduce pressure on the grid in times of high demand. For wind power preliminary results from a grid impact study for Sulawesi suggest that there might be less capacity to interconnect than initially thought. South Sulawesi was selected by many project developers due to the relatively inexpensive land cost, the fairly sizeable grid and expected growth in power consumption, and because it has one of the highest wind resources in Indonesia.

PLN issues an annual document called the Electricity Supply Business Plan (RUPTL) that outlines in detail the long-term plans for generation, distribution and transmission growth. In many cases the document includes specific projects, especially for generation projects above 10 MW and for transmission projects. Distribution planning and generation projects below 10 MW generally are done by regional PLN offices and fall fully under their authority. While the plan is detailed and includes specific figures for geothermal and hydropower capacity by location, it does not provide this level of detail for the other renewable energy technologies. Furthermore, as shown in table 3, the renewable energy targets included for 2025 are significantly below those set by MEMR. This implies that current long-term grid plans of PLN are not designed for achieving the ambitions of REmap, or even the Reference Case.

Finally, current procurement strategies (such as high contracted hours from non-renewable IPP generations, take-or-pay gas supply contracts, and diesel equipment rental contracts) discourage dispatch strategies that favour renewable energy generation. These contracting strategies result in dispatch merit orders that are likely to curtail renewable energy generation.

Opportunities

- Targets for renewable power technologies should be aligned between PLN and MEMR. Detailed plans for individual grids and their potential to absorb VRE are recommended given the fragmented nature of Indonesia's electricity system. PLN will need to incorporate specifically in its plans the expected increase in VRE by technology and location, and also could consider developing a plan for transmission and distribution requirements across locations for a case of high VRE uptake, such as the one suggested by REmap.

- Important for VRE integration is developing sound market conditions as well as grid management practices and dispatch strategies that incorporate the concept of spinning reserves based on generation forecasting of VRE power plants. In the short term, VRE power plants could be required to submit 48-hour, 36-hour and 24-hour generation forecasts. These reports can then be used to plan PLN's dispatch orders so that there is always available spinning reserve.

- PLN could introduce a different procurement strategy that will take advantage of cost savings of the use of renewable energy sources and that provides for priority dispatch of VRE. Contracts with non-renewable IPPs could be more flexible instead of locking in a high number of contracted hours. In general, PLN needs to integrate its procurement strategies with system planning and grid management protocols to allow for the prioritisation of renewable energy use.

- The addition of energy storage can help stabilise the grid while incorporating higher levels of VRE. Residential and commercial storage options can be implemented with appropriate support mechanisms, as has been done in various other countries (*e.g.*, Germany). The potential for more electric vehicles and electric two- and three-wheelers and being able to use them as energy storage provides another solution. Vehicle-to-grid technology can be implemented for grid-stabilising storage as well as time-shifting storage.

- Capacity building with relevant stakeholders (in particular PLN) in Indonesia for how to plan for an electricity system with higher levels of VRE in the grid is recommended. The Danish Energy Agency (DEA) and the United States Agency for International Development – Indonesia Clean Energy Development (USAID-ICED) project have already started this effort. DEA is currently conducting a study on wind power integration into the power system, to address challenges concerning the integration of VRE and to make detailed recommendations on, for example, required changes to policies and regulations. USAID-ICED is conducting a specific study of the South Sulawesi grid to incorporate a planned 200+ MW of wind power plants (USAID, 2015).

Cost recovery for PLN

Another major issue today relates to the costs to PLN that come with renewable energy projects. Currently, PLN has two main sources of income: payments from consumers and government compensation for subsidies to consumers reflected in lower electricity prices. No additional compensation is provided to PLN for the feed-in tariffs for renewable energy projects, which generally exceed the electricity prices that PLN charges to consumers. The compensation to PLN for subsidies to electricity consumers is calculated based on the difference between the (subsidised) prices and the estimated production cost for PLN (which includes generation, transmission and distribution, and overhead cost). This compensation is a legal term specified in the Ministry of Finance's regulation and has a specific methodology for calculations; it currently cannot be used to cover PLN's additional costs for mandated renewable energy feed-in tariffs. Furthermore, PLN is under pressure to lower its dependency on income from this compensation and to reduce its overall production cost base. These dynamics limit PLN's ability to sign PPAs for renewable projects under existing feed-in tariff programmes.

As mentioned in section 2.1, PLN also is negotiating PPA agreements directly with developers, mainly for larger-scale projects. While there is a document from PLN that outlines this process, it is still lacking in describing the requirements for different stages of the development process (PLN, 2013). As an example, one of the steps is called "Proposal Evaluation", but the document does not mention what the criteria are for projects to move to the next stage in the process. For the required feasibility studies a suggested table of contents is provided, but no specific criteria beyond this are outlined.

Furthermore, part of the project approval process by PLN includes a financial viability assessment, where the return on equity to investors is capped at 14%. If the outcome of the assessment is that the PPA is higher than the current production cost at the site, then PLN's recommendation to MEMR is to conditionally reject the project. This recommendation includes the additional costs that will be required to cover the gap between the required tariff and the cost of generation. If MEMR then agrees to fund the gap, PLN will accept the project, although as of now it is not clear where the funds will come from.

Opportunities

- A new scheme or fund is recommended for renewable energy projects that covers the gap between the mandated renewable energy feed-in tariffs and the revenues that PLN receives from consumers. This would allow for PLN to purchase more renewable energy through feed-in tariff regulations. Feed-in tariffs need to be high enough to attract early investors, while PLN needs assurance that the additional costs will be borne by the government. Setting up this fund should involve not only PLN and MEMR, but also the Ministry of Finance.

- The process for PLN to negotiate agreements directly with developers for renewable energy projects should be more standardised. Detailed requirements for feasibility and interconnection studies should be provided to ensure that projects meet standards while streamlining what different developers submit. It also should be clarified where funding will come from and in what time frame, to reduce uncertainty in the market. As long as the process is clear and transparent, this will allow more renewable energy projects to be developed and implemented at an appropriate tariff and reduces the issue of cost recovery to PLN.

- A consumer tariff structure based on the level of electricity consumption could be considered, with higher prices for larger users. This would encourage larger energy users both to implement energy efficiency measures and to use renewable energy (such as rooftop solar PV) to reduce their grid energy consumption.

Off-grid deployment

There are significant opportunities for off-grid deployment of renewables in rural areas, as over 12 000 villages are currently not yet electrified. In the Reference Case, it is assumed that 2.1 GW of additional solar PV mini-grids will be installed through active efforts by the government and PLN to provide electricity to 1.1 million households, in addition to about 300 MW of off-grid and mini-grids based on hydropower. Remote areas in Maluku & Papua and Sulawesi & Nusa Tenggara represent a majority of planned deployment.

In achieving this ambitious target, the lack of bankable off-takers represents a key barrier. While some project developers might be willing to accept tariff payments directly from communities, this would come with challenges related to economic viability, given the high number of fragmented un-electrified villages with low levels of demand and because people are unable to pay the electricity price that is required to cover capital expenditures and operational expenses.

Several hundred solar PV- and micro-hydro-based micro-grids have been installed in Indonesia in recent years. This has been the result of several programmes, including innovative uses of public-private partnerships, that have been supported by international organisations, foreign governments and various Indonesian ministries and agencies. This has led to an active market for micro hydro where communities, local private fabricators and equipment suppliers have formed an ecosystem for sustaining a market. However, issues have emerged as well. Some systems experienced failures within a short time of commissioning. Despite efforts by the German Agency for International Cooperation (GIZ) to train many of the villages in the basic O&M of the systems, there is still a lack of capacity in being able to troubleshoot and fix more complicated failures.

Furthermore, as communities get access to electricity, their consumption is likely to increase. Often this can be significant, as each household might add more electrical equipment such as fans, televisions and refrigerators. This brings about issues related to the scaling of off-grid solutions and has resulted in discrepancies between the size of the power system installed and the increasing local energy demand over time. Further scaling capacity might be challenging for micro hydro in particular, whereas for solar PV this is less of an issue.

Finally, in many cases, the public grid will eventually arrive and the community is faced with a choice between the micro-grid and the public grid. In many countries this has posed challenges to the continued financial viability of the micro-grid, as villages have an incentive to connect to the main grid instead if this comes with lower electricity prices (IRENA, 2015c, 2016e).

Opportunities

- Increasing PLN's Public Service Obligation budgets to build and own distribution networks in the locations where off-grid projects are implemented could be considered. These budgets are now typically used for grid extension projects to reach currently un-electrified communities. However, a significant portion of an off-grid project's capital expenses come from installing the distribution network and the household connections. If PLN is able to provide the funding or even to build the distribution network and household connections, this can reduce the capital investment required by project developers.

- To further improve the business case of off-grid renewables to project developers, establishing larger off-grid working areas or concession areas that encompass multiple villages could be considered. The concession areas could be determined by PLN and MEMR and could provide project developers with the first right of refusal to supply electricity for this area. This allows for lower system installation cost, while also allowing for the latest technologies to be used that are only economically viable at scale.

- There is a need for an entity that is responsible for overseeing the continuing O&M of the system, including troubleshooting and component replacement. It is important that local community members are involved, for example to perform basic O&M. Local engineers and technicians from the regions could be trained to provide support on more complicated troubleshooting and operational issues.

- Standardised survey methodologies to design off-grid systems on a community level are recommended. A standard energy needs requirement survey and a resource assessment survey will need to be performed on each community and incorporated in key design elements (for example, size and technology) of the off-grid system. Expected additional growth in electricity consumption should be factored into the design of systems and technology choice, as certain technologies are more flexible to scale up (*e.g.*, solar PV) than others (*e.g.*, micro hydro).

- To avoid stranded micro-grid assets, the strengthening of regulatory frameworks to allow for integration of mini-grids with the public grid should be considered. One approach could be to introduce a concession model, where developers can obtain a concession for a number of years of operation, within which all assets are depreciated. Should the grid arrive before assets are fully depreciated then the developers are guaranteed compensation at a pre-determined level (IRENA, 2015c). Other options should be considered as well to increase participation of the private sector, such as including multiple exit options on arrival of the grid, in line with recent draft guidelines for micro-grids in India (MNRE, 2016).

Project finance

In general, financing costs are high in Indonesia, and this presents another challenge for renewable energy projects which typically come with long-term PPAs. The typical commercial cost of capital in Indonesia is higher than 10% for the local currency, and also for USD- or Euro-based lending. This results in a relatively high PPA tariff to ensure that the projects are financially viable to investors. At present, larger projects are funded through foreign equity and lending institutions, often through development funds and private equity. Recently, the government has indexed many of its latest renewable energy tariff regulations to the USD, which helps in making projects more accessible to funds that are USD-based.

With the increase in recent years in international climate funds, significant additional capital should be available through these channels for renewable energy projects in Indonesia. The primary barrier holding back the use of these funds is the current lack of bankable projects. Most funds will only finance projects with signed PPAs, and few projects with signed PPAs are currently available (due in part to cost recovery issues for PLN, as discussed above). This also is due to the lack of project development equity to properly develop projects with high-quality site surveys, pre-feasibility studies, grid interconnection studies and other crucial steps to reach a signed PPA.

In addition to the high cost of capital, for both equity and loans, there is a shortage of local project financing capacity. Efforts are under way to train local bankers (through programmes of, for example, DIE and ACE), by using learnings from projects in Thailand and Malaysia. However, banks in Indonesia still have only a few people assigned as assessors of renewable energy projects. For smaller projects, the types of local financing that are available are mostly collateral-based. In some cases, the project sponsor's balance sheet is the collateral, effectively becoming corporate loans.

Opportunities

- Further strengthening local project finance capabilities will be an important step for the accelerated deployment of renewables. Increasing awareness at commercial banks about the opportunities, as well as providing clear signals from the government regarding long-term support for renewables, could help banks to assign more resources to renewable energy project finance.

- Creating a standard procedure and performance indicators for project development documents will be important to ensure that projects can be financed. In addition, providing funds for project development (*e.g.*, in the form of convertible loans) could vastly increase project development activities in Indonesia, which would increase the utilisation of international climate funds for renewable energy projects. Careful consideration will have to be made to ensure that the deliverables of the project development phase meet international standards and industry best practices, while developers need to be accountable and transparent about the cost incurred.

- Alternatively, providing government loan guarantees for larger projects could be considered to lower risk to investors (IRENA, 2016f). This could be especially interesting for projects/ technologies where the lack of project financing is a main bottleneck. Once successful projects have materialised the need for loan guarantees will decrease.

Land acquisition and community involvement

Many renewable energy technologies require relatively large areas of land, which is especially the case for solar PV projects. However, there are still issues around legal land ownership. Recently, for example, the Jakarta government questioned the purchase of land from a private owner and later found that it already owned the land since the 1960s (Anya, 2016). In more-rural areas where documentation and administration are still not electronically processed and recorded, it is even more difficult to track land ownership.

The cost of land can be a significant portion of the project cost. Regions where the grid can accept more VRE typically are relatively more economically developed, such as Java. Therefore, land costs in Java are significantly higher than in Papua, for example. However, in Papua, the potential for VRE is relatively more limited due to constraints on the demand side. These considerations are not reflected in current feed-in tariff regulations for renewables, which generally are lower for projects in, for example, Java than in more remote locations.

Also, local communities play a large role in the land acquisition process, and it can take a long time for project developers to obtain the required land. There also have been reports of asking prices for land going up significantly when developers make clear their intention to develop the land for projects. Community involvement therefore is an important part of the development process.

Opportunities

- Cost-of-land differences across different locations in Indonesia could be reflected more in feed-in tariffs. Alternatively, the government can take a more active role in providing lands, especially in locations with a large potential for renewables (such as Java and Sumatra). Specific plots of (non-productive) lands could be acquired and provided for renewable energy projects, ideally with interconnection points on-site as well as pre-approved environmental impact assessments. This would reduce not only the land acquisition cost, but also the interconnection cost, and would simplify the permitting process.
- Local communities need to be involved early in the project development phase by engaging with the community leaders and local government. Whenever possible, local community members should be employed by the project. Also, providing additional services on behalf of the project to the surrounding communities – such as additional electricity, clean water and sanitation facilities – will be important to increase community buy-in and increase the probability of acquiring land. Existing agricultural lands could allow for the addition of solar panels and wind turbines on-site, increasing revenues to local farmers and reducing land acquisition issues.

Technology-specific barriers and opportunities

Beyond the above-mentioned barriers that apply to all renewable energy technologies, there are additional barriers that relate to specific technologies. An overview of these barriers and opportunities is provided in table 16.

Table 16: Technology-specific barriers and opportunities in the power sector

Technology	Barriers	Opportunities
Solar PV	• Complicated permitting procedures for ground-mounted projects add to project development cost • A net metering system for rooftop solar PV is in place, but no compensation is provided beyond (future) own consumption, and a minimum payment is charged each month for having a grid connection	• Simplify permitting procedures for ground-mounted systems • Provide additional compensation to excess electricity sold to the grid from rooftop systems (*e.g.*, allow for payment of the minimum monthly charge through the credit mechanism)
Hydropower	• Project-specific issues relate to access to the project site, environmental impact and social issues, catchment area protection, as well as water rights management • Historical data are often lacking at a regional level; in many locations there are no flow data or flood and groundwater data beyond the last 5-10 years • Hydropower projects are planned involving different levels of government, while advantages of hydropower projects to local communities might not be optimally communicated	• Strengthen capacity with local companies to ensure that studies are based on industry best practice and are bankable for project finance • The Indonesian Meteorological Agency (BMKG) could install additional monitoring equipment and collect information regularly. These data could be made openly available to any project developer to be used as the basis for project assessment • Highlight the large opportunity for local employment and industry creation to local authorities to increase local interest

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Technology	Barriers	Opportunities
Bioenergy	• High administrative costs and permitting procedures make it challenging for industry to interconnect bioenergy power to the grid • Potential producers often do not consider bioenergy power generation as part of their core business and/or are not aware of the potential for bioenergy power to reduce fossil fuel consumption, limiting the deployment of bioenergy capacity • The feed-in tariff for biomass power projects currently does not apply to projects larger than 10 MW, which reduces the potential for producers that do intend to connect to the grid to reach economies of scale	• Reduce permitting procedures and administrative costs for interconnection of bioenergy power generation by industry • Increase awareness among industries about the potential that bioenergy offers and stimulate the use of CHP-based bioenergy • MEMR could consider increasing the maximum size of bioenergy power projects to qualify for the feed-in tariff to beyond 10 MW to allow for economies of scale to reduce generation cost
Geothermal power	• High upfront exploration cost and risk are associated with projects • Geothermal tenders have often attracted unqualified bidders, which delayed the execution of projects • Approvals from the Geothermal Fund Facility (GFF) for exploration or projects have been very limited to date	• Engage in knowledge and capacity building with relevant stakeholders to ensure that projects can be implemented within budget and on time • The GFF needs to be able to allow projects with a higher risk profile to be eligible for funding • Other options include government guarantees (on loans), or developing a revolving fund sharing the cost of the exploration and discovery/confirmation stages of a geothermal project
Marine energy	• The realistic deployment potential for the different types of marine energy around the many islands of Indonesia is not fully understood as of yet, also taking into account the availability of local grids and estimated project costs • Marine energy is an emerging technology without a mature global market, posing technology risks to achieving the targets in the 2030 time frame	• Expand assessment of the resource potential and economic deployment potential of marine energy in the short and long terms; identify separately the potential for smaller-scale (off-grid) projects and larger-scale projects • Focus on smaller-scale projects close to land first to build local capacity and demonstrate the technology potential • Consider expanding R&D efforts with a focus on developing innovative applications of marine energy for remote communities (such as water pumping, desalination, ice making)

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Technology	Barriers	Opportunities
Wind power	• There is no feed-in tariff for wind power, and projects under way have been negotiated directly with PLN. Without a transparent competitive bidding process in place, potential issues (*e.g.*, not selecting the best parties for projects and/or at a price that is too high) could get worse as the availability of good sites (*i.e.*, with wind speeds above 5 metres per second near grids with significant load) is limited • Some developers are investing significantly in project development efforts in Indonesia – such as the installation of meteorological instrument masts – without a clear understanding of the risk/rewards. This could lead to disappointment in the future if projects are not awarded to these companies, and could reduce overall interest in the Indonesian market	• Consider including wind power in feed-in tariff programmes. Alternatively, introduce auction schemes that are transparent, simple and fair to increase the confidence of project developers* • Provide developers with a clear understanding of upcoming project opportunities and transparency on the process for selecting winners

* For an analysis of auction design options, best practices on implementation, and policy recommendations, see *http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Auctions_Guide_2015_2_policies.pdf*

7.2 Barriers and opportunities in the end-use sectors

Buildings

The REmap Options indicate the potential for solar thermal collectors to meet 40% of solar water heating energy demand by 2030. Solar thermal collectors for water heating are already very popular in other parts of Asia, most notably in China. In Indonesia, limited awareness among building owners and a lack of design standards are seen as main barriers to deployment. Solar cooling technologies (both active and passive) hold potential towards meeting the rapidly growing demand for air conditioning in urban areas, but awareness among building owners of its potential is currently lacking in Indonesia.

Opportunities

- Additional efforts to capture the potential of solar water heating by national and local governments are needed, for example through the inclusion in building codes. Many cities around the world already have in place solar thermal ordinances that require new buildings – especially larger ones – to install collectors.

- As the global market for solar cooling is at a more nascent stage, stimulating demonstration projects on commercial and public buildings to create awareness of its local potential would be advisable. For residential buildings, where the cooling demand is generally smaller, a separate programme is needed.

Industry

In industry the REmap Options consist of solar thermal and the additional use of bioenergy for process heat (discussed in section 7.3). For solar thermal the potential is mainly in the natural rubber, food and textile industries that are characterised by low-temperature process heat. While these industries are less energy-intensive per plant, in aggregate they represent large energy-consuming industries that rely on low and medium heat for their processes, particularly suitable for solar thermal. The total potential for solar thermal heating in industry is estimated at 70 PJ, representing 20% of the total energy use for heat in above-mentioned industries. Similar to the residential and commercial segments, limited awareness of the potential for solar collectors to supply heat for industrial processes poses a significant barrier. While the demand for heating in industry is continuous, solar thermal collectors provide an intermittent supply of energy. For existing plants, space limitations might pose another barrier, especially if the buildings are not able to accommodate collectors on their rooftops or if there is no sufficient on-site area.

Opportunities

- A specific programme to build local awareness and capacity, particularly highlighting the potential for solar thermal energy to substitute costly petroleum products, is needed. In turn, this could improve the competitiveness of Indonesia's industry. Local demonstration projects would be a good option to consider as a first step.

- Consider solar thermal storage capacity and/or hybrid solutions (with fossil fuels) in the design and construction of new industrial plants. For existing plants, concentrated solar thermal (CST) solutions can be an option given that they use less space, but that will depend on whether there is demand for higher-temperature steam and on the cost of the incumbent, since CST is often more expensive.

Transport

The ambitious blending mandates for ethanol (20%) and biodiesel (30%) for 2025 onwards currently dominate the Indonesian outlook for renewables in transport (further elaborated in the next section). However, electric vehicles and two- and three-wheelers provide major opportunities that are currently unaddressed. With the REmap Options the potential by 2030 for 6% of the vehicle stock and 20% of all motorcycles and scooters to be electric has been identified, based on the expectation of a rapid continued increase in vehicle penetration. In remote areas and islands, electric vehicles and electric two- and three-wheelers are good solutions given the relatively short travelling distances. In larger cities electric mobility can play an important role in mitigating air pollution. However, at present the infrastructure is lacking to support the increased use of electric mobility, and only a few companies sell electric cars, scooters and motorcycles.

Opportunities

- To accelerate the uptake of electric vehicles and electric two- and three-wheelers, several actions should be considered. Infrastructure investments, such as charging infrastructure for electric vehicles and electric two- and three-wheelers at large parking lots in cities, should be combined with support policies (*e.g.*, tax incentives to reduce the cost of electric vehicles) to kick-start the market. This could happen at the national government level, but also at the local government or city level, as has been the case in many countries around the world.

- To maximise the potential of localisation benefits (such as job creation and human capital building), the domestic industry should be involved early on. Indeed, almost as many cars, motorcycles and scooters are produced and sold in Indonesia every year (ASEAN Automotive Federation, 2016). Incentivising local industry with the production of electric vehicles, motorcycles and scooters for the local market could be an effective way to achieve faster market growth.

7.3 Ensuring the sustainable use of bioenergy

Bioenergy plays a major role in Indonesia's energy system across all sectors – primarily in the form of liquid biofuels in transport, waste and residues for process heat in industry – and it is used by many households for cooking. Indonesia's rich endowment of bioenergy resources provides significant opportunities for reducing fossil fuel use and adding economic value. However, barriers on both the supply and demand side will have to be addressed for the potential to be used in a sustainable way.

Supply side

Biodiesel

The blending mandates that are targeted for 2025 onwards (E20 and B30) are assumed to materialise in the Reference Case, resulting in the need for about 25 billion litres of liquid biofuels (13 billion litres of biodiesel and 12 billion litres of ethanol) in 2030, based on projections for total gasoline and diesel use. These ambitious policies will significantly reduce fossil fuel dependence in transport.

Indonesia has a long history in the production of biodiesel. In 2015 less than 1 billion litres of biodiesel was blended but the expectation for 2016 is that this could increase to 3.2 billion litres. Biodiesel is currently produced at scale from palm oil. However, based on the assessment of the sustainable bioenergy supply potential, there is no potential for energy crops (palm oil, but also other crops) on suitable lands (as per the FAO definition) beyond those that are currently used. This is because forests cover large parts of the remaining suitable land (and are excluded) and because agricultural lands are expected to expand to meet the increasing demand for other crops. With the expected yield increase of 0.7% per year for palm oil up to 2030, the implied supply potential (162 PJ) in that year translates into 2.5 billion litres of biodiesel, below the expected production level of biodiesel for 2016. To meet the growing demand for biodiesel from palm oil in Indonesia, two sources of additional production are considered: using degraded lands and further increasing yield improvements.

There is a lot of degraded land in Indonesia, with estimates ranging between 12 Mha and 74 Mha depending on different definitions and suitability criteria (Wicke *et al.*, 2008). In recent years, more region-specific studies have shed new light on the specific potential for energy crops on such lands. For degraded lands suitable for palm oil, between 0.5 Mha and 7 Mha of land in West and Central Kalimantan was identified. The wide range is due to the degree of suitability and sustainability criteria (WRI, 2012). Another study on North and East Kalimantan found the potential for an additional 0.7 Mha to 1.0 Mha from responsible land zoning and potential agricultural development on underutilised lands (Van der Laan *et al.*, 2016). At the low end of the range (with a higher probability of ensuring sustainable practices) this implies about 1.2 million Mha of potentially suitable degraded lands on Kalimantan for palm oil production. At current average yields of 3 tonnes of crude palm oil per hectare per year (t CPO/ha/year), this theoretically could be used to produce about 3 billion additional litres of biodiesel from palm oil. Additional potential for degraded lands is likely to exist on Indonesia's other islands as well, mainly on Papua and Sumatra.

While degraded lands certainly provide opportunities, barriers exist to fully utilise degraded lands for biofuel production, especially within the 2030 time frame. The degraded lands often are scattered plots of less than 1000 ha each, which is below the required 5000 ha required for one palm oil mill. Without economies of scale, this reduces the economic viability to larger plantations and limits their interest in exploiting these lands. The regulatory frameworks and capacity to implement at the district level also are reported to be insufficient for the sustainable use of many of the degraded lands, especially with concerns over land-use rights. Furthermore, there is competition over these degraded lands with other crops, most notably rubber and rice, for which demand is also growing fast.

Improving yields will be important to increase the production of palm oil based on lands currently in use. Yields have already improved in various locations in recent years through replanting and improved practices. On average, yields in Indonesia are currently around 3 t CPO/ha/yr, although a big difference in average yields exists between smallholders – about 2 t CPO/ha/yr – and large holders – at about 5 t CPO/ha/yr. A yield of 5.7 t CPO/ha/yr was observed on plots with best-management practices on six plantations across Sumatra and Kalimantan between 2006 and 2011 (IFC, 2013). If by 2030 all palm oil plantations would be achieving a yield of 5.7 t CPO/ha/yr – instead of the 3.3 t CPO/ha/yr in the baseline projection based on an annual yield increase of 0.7% – an additional 27 million tonnes of crude palm oil could be produced per year. If, for example, half of this would be used for the production of biodiesel, an additional 12.8 billion litres of biodiesel could be supplied.

This shows why the further increase of yields has a lot of potential. However, increasing average yields to this level, especially by 2030, would come with challenges. Reaching the large number of smallholders, where most of the potential to increase yields exists, will be a first challenge. Although exact estimates on the number of smallholders are unavailable, there could be as many as 1.4 million in operation today (Rainforest Alliance, 2016). Combined they account for about 40% of the total production of palm oil in Indonesia. If they all could be reached, convincing them all to implement different practices would be cost- and time-intensive. Also, improving yields will come with funding requirements, and many smallholders have limited access to finance and are unlikely to be able to cover the upfront investment.

Ethanol

There exists large potential to scale up the production of ethanol in Indonesia. Ethanol is currently produced at a small scale in Indonesia, despite the blending mandates in place and the ambitious targets for the future (E20 in 2025). Sugar cane is currently the main feedstock for ethanol production, although cassava also has potential. For both, there is competition over the crop's use for food. The production of advanced ethanol – for which grasses and woody crops on degraded lands could be used – has significant potential, although cost competitiveness is an issue today. Currently more than 90 projects for the production of advanced biofuels around the world are at various stages of development (IRENA, 2016g). Although none of these is based in Indonesia, and only one is based in Southeast Asia, these industry development play an important role to improve conversion technologies and reduce cost.

Industry

Beyond the use of liquid biofuels, bioenergy use in industry (mainly from solid biomass) will more than double in the Reference Case, while with the REmap Options it would nearly triple. The large contribution of bioenergy to supply process heat in Indonesia is encouraging, as industry remains a difficult sector in many countries in terms of increasing the penetration of renewable energy. The increased use of bioenergy in industrial processes in Indonesia comes with some barriers though. Agricultural residues form the largest feedstock for industrial bioenergy use in Indonesia. The seasonality of feedstock supply and the continuous energy demand of plants is a challenge, especially if storage space is unavailable. Another barrier is the relatively high transportation cost for feedstocks to maximise the use of bioenergy use across different locations. Palm oil residues have great potential for bioenergy but compete with other uses. Trunks and leaves generally are left on the ground to replenish the topsoil and act as a natural fertiliser. Limiting the potential for using wood waste for bioenergy, for which the REmap Options also have identified considerable potential, are regulations on wood recycling which are currently lacking (Sutapa, 2014).

Demand side

The challenges on the demand side for liquid biofuels relate mainly to the compensation required for blending, and to some extent to technical limitations. With low oil prices today, blenders in Indonesia require compensation given the higher production cost of liquid biofuels. A fund currently is in place to provide this compensation for biodiesel in transport, but not for its use in other sectors. A subsidy is currently unavailable for ethanol. There also are concerns that the funding for subsidised biodiesel will be inadequate if oil prices remain at low levels (Asmarini, 2016). For Indonesia to fulfil its blending mandates across sectors, these compensation issues would need to be addressed. Some concerns also exist over the technical challenges that come with the blending of liquid biofuels. PLN stated that using B30 could cause damage to its power generators (Munthe and Asmarini, 2016). Although BPPT has confirmed that B20 is safe for use in automotive applications, the automotive industry voiced concerns over how engines might be affected (Cahyafitri and Yulisman, 2015; Paryanto, 2015).

In industry the financial viability of projects and the lack of access to grids pose barriers to the accelerated use of bioenergy. For using palm oil residues, new mills have boilers that can use the biomass waste from the mill (such as empty fruit bunches and kernel shells), but old mills do not have this capability. Retrofitting comes with significant cost, which with today's low oil prices puts pressure on its business case. For biogas from palm oil mill effluent, REmap has identified significant potential, and the recently signed PPA with PLN for a 2.4 MW biogas plant from POME brings positive news (Sewatama, 2016). In many locations, however, the lack of access to grids remains an issue; IPP projects are the main way for POME-based biogas projects to be viable.

Finally, with the REmap Options an additional 8 million households – who would still rely on traditional uses of bioenergy for cooking in the Reference Case – will use modern cook stoves using solid biomass and ethanol. While these modern cook stoves (such as rocket stoves and ethanol cook stoves, which have been a popular option in parts of Africa) come with a significant upfront investment (around IDR 30 000) for low-income households, over time this is offset by reduced fuel cost and health benefits. The accelerated deployment of biogas digesters also will come with challenges. While the barriers and opportunities are largely similar to those for cook stoves that use solid biomass or ethanol, there is additional negative social stigma for the use of biogas, for example from public toilets. Although the Indonesia Domestic Biogas Programme is making progress, the number of installed biogas digesters in the country – at around 15 000 by the end of 2015 – is still modest compared to the potential. For all modern cook stoves using bioenergy, the subsidised price of LPG canisters for low-income households is an additional barrier.

Opportunities

- To ensure the sustainable use of bioenergy, the development of a comprehensive Indonesian bioenergy programme is recommended (see table 17). This should not only focus on the production of liquid biofuels but have a broader scope, as there are many interlinkages between sectors. Palm oil producers, for example, not only supply feedstock for biodiesel production, but also play an important role in increasing the use of residues and waste in the production of heat and electricity.

- The objectives of the programme should include a review of biofuel blending mandates for Indonesia, addressing current barriers on both the demand and supply side. One of the outcomes of such an assessment would be a more gradual roadmap for increasing blending mandates over time, with a more detailed assessment for each step as to how the increase is to be achieved in a sustainable manner.

- Similar long-term plans with intermediate targets (either a percentage mandate or a volumetric target of consumption) and monitoring towards these targets is required for the use of solid bioenergy and biogas in industry and the power sector. Policies should be evaluated and adapted as required on a regular basis towards meeting the targets.

- On the supply side, advanced biofuels should be a part of the solution. As mentioned, significant potential has been identified for perennial lignocellulosic feedstock which can be used for the production of advanced ethanol. This is an area where Indonesia could leverage its experience in biofuels while focusing R&D efforts on the local commercialisation of such technology.

- Other innovative supply-side approaches are also recommended. For example, there is the potential for ethanol production from the pulp produced as residues of cassava starch – instead of using the edible tuber parts – to avoid competition with the demand for cassava as food (Hermiati *et al.*, 2012). The saps of the oil palm trunks that currently are left after trees are felled – and that emit a large volume of greenhouse gases in the form of methane – could be used to produce ethanol as well as other biomaterials, as they have a high glucose content (Kosugi *et al.*, 2010). A diffusion of such types of practical and climate-smart technologies and practices also will contribute to Indonesia's zero-deforestation policies.

- For industry, adequate planning based on anticipated heating demand and customised storage solutions for bioenergy feedstock are recommended, especially for new industrial plants. In addition, a detailed plan is recommended to identify where the main feedstock sources are for the use of bioenergy in industry, taking into account also access to the power grid incorporating PLN's transmission and distribution expansion plans up to 2025. Government rebates for retrofitting boilers to use biomass waste from mills could be considered.

- On the demand side, funding for liquid biofuel blending should be allocated in line with the targeted increase in blending mandates, increase of fuel usage, and oil price expectations. Concerns over technical limitations on using liquid biofuels should be taken into account and addressed early on. Programmes to reduce food waste would increase the potential for using local agricultural produce as bioenergy feedstock, and expanding the regulatory framework for wood recycling could support the additional use of wood waste for bioenergy.

- To expand the modern use of bioenergy for cooking, the efforts of the Indonesia Clean

Stove Initiative – undertaken by the World Bank and MEMR – should be expedited. Phase III of this programme, which includes a scaled-up national programme for clean biomass cook stoves, was envisioned to begin in 2014 but has not started to date. Creating awareness of the viability of the solutions available in addition to expanding efforts in testing, setting standards and strengthening supply chains (especially in remote areas) will be crucial for the accelerated uptake of modern cook stoves. Local capacity building and options for local manufacturing are important for creating buy-in at the community level. The Indonesia Domestic Biogas Programme also would need to be scaled up further if the ambitions in the Reference Case (an estimated 2 million biogas digesters to be in use by 2030) are to be achieved. Reducing subsidies on LPG canisters over time could support the accelerated uptake of modern cook stoves using bioenergy.

- Broad alignment among different stakeholders on the demand side, supply side and in government is required. On the demand side this includes relevant industries that can use bioenergy in their processes, key companies responsible for the blending and distribution of fuels, as well as automotive companies and PLN. On the supply side this includes biodiesel producers, large producers and sector representatives of bioenergy feedstock, as well as researchers and organisations involved in the assessment of the potential for using different feedstock. Government bodies that should be part of the discussions are, among others, MEMR, the Ministry of Agriculture, the Ministry of Land and Spatial Planning, the Ministry of Environment and Forestry and the Ministry of Research, Technology, and Higher Education.

- Although it will be difficult to satisfy all stakeholders, ultimately the objective should be to maximise the benefits to society of the large bioenergy resources that Indonesia is endowed with. The indicators as developed by the Global Bioenergy Partnership and the recommendations from the pilot test in Indonesia should be incorporated to ensure the environmental, social and economic sustainability of bioenergy use in Indonesia.

Table 17: Overview of a comprehensive bioenergy programme for Indonesia

	Demand side	**Supply side**
Objective	Maximise the benefits to society of Indonesia's endowment of bioenergy resources	
Target setting	Roadmap with gradually increasing targets for bioenergy use across sectors	Assessment of different feedstock to set targets while ensuring sustainability
Regulation	Support policies (*e.g*,. to reduce financing cost) as well as mandates, including the periodic review of effectiveness	Regulations to address bottlenecks (*e.g.*, land-use rights), support yield increases and use of degraded lands
Innovation	Programs focusing on, *e.g.*, reduction of food waste, demonstration projects for biogas from palm oil mill effluent, etc.	Targeting for advanced biofuels, promotion of innovative feedstock uses (*e.g.*, ethanol from cassava pulp), expansion of R&D
Stakeholders	Relevant industries, biofuel blenders, car manufacturers, PLN	Biofuel producers, agro industry representatives, research institutions
	MEMR, Ministry of Agriculture, Ministry of Land and Spatial Planning, Ministry of Environment and Forestry, Ministry of Research, Technology, and Higher Education	

8 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

REmap has identified significant potential for renewable energy in Indonesia across sectors and technologies. To accelerate the uptake of renewable energy, several challenges need to be addressed. Below is provided a summary of these challenges and related policy suggestions. In the **power sector,** barriers in key areas need to be addressed, along with some technology-specific challenges.

Grid integration of VRE needs to be a focus area given the highly fragmented nature of Indonesia's grid, with many small grids in remote locations. Detailed transmission and distribution expansion plans are provided on an annual basis by PLN, but location-specific plans for VRE (solar, wind and marine) are not included. The projected deployment for each of the renewable energy technologies is also below the ambition set forth by the government.

- Align targets for renewable energy deployment and incorporate the expected deployment of VRE in transmission and distribution plans. Consider the potential of energy storage (including from electric vehicles) for the smoother integration of VRE and introduce priority dispatch for renewable energy generation by changing the structure of non-renewable energy IPPs.

Cost recovery for PLN remains an issue as feed-in tariffs for renewable energy generally exceed the price that PLN charges to consumers of electricity. PLN is also negotiating PPA agreements directly with renewable energy project developers, but requirements for parts of the approval process are not standardised. Furthermore, it is unclear if and when funding for these projects will be provided.

- Identify funds that that could cover the gap between renewable energy PPAs/feed-in tariffs and the revenues that PLN receives from consumers. The process for PLN to negotiate PPAs directly with developers for projects should be more standardised and should include detailed requirements for feasibility and interconnection studies to ensure that projects meet predefined standards.

Off-grid areas have been identified as having great potential for solar PV to electrify remote villages. The lack of bankable off-takers, operational issues due to the insufficient O&M of systems, inadequate scaling of systems, and the risk to the viability of systems when the main grid arrives are key challenges in this area.

- Establish larger off-grid working areas that include multiple villages to achieve economies of scale and consider expanding PLN's responsibility to build and own distribution networks in these areas. The creation of an entity to oversee O&M of systems, involving local communities, expanding the use of standardised survey methodologies to ensure that systems are scaled adequately, and strengthening regulatory frameworks on the integration of mini-grids with the public grid are also recommended.

Project finance opportunities for renewable energy projects in Indonesia are limited at present, as local banks do not allocate large resources to this segment. The inflow of international climate funds is also limited, due mainly to the lack of project development equity to develop projects with proper site surveys, pre-feasibility studies and grid interconnection studies to reach a signed PPA.

- Increasing awareness at commercial banks of opportunities and clear signals from the government on long-term support for renewables could help banks to assign more resources to renewable energy project finance. Creating standard procedures and performance indicators for project developers will be important to ensure that projects can be financed. Loan guarantees can be considered by the government to further lower the risk to investors.

Land acquisition and community involvement issues revolve around a lack of clarity on land ownership in many locations, as well as costly and time-consuming processes to acquire land, partly as a result of limited community buy-in for renewable energy projects.

- Local communities need to be involved early in the project development phase, and providing additional services to communities (such as additional electricity, clean water) could be considered. Large differences in the cost of land should be reflected more in the regional feed-in tariffs, and the government could consider taking an active role in providing lands for projects. Existing agricultural lands might have potential to integrate solar panels or wind turbines.

Technology-specific requirements (for solar PV, hydropower, geothermal power, bioenergy power, wind and marine energy) consist of, for example, increasing awareness of solutions, building local capacity and maximising local added value, streamlining permitting and regulatory frameworks, and expanding resource assessments.

- Beyond the power sector, REmap suggests large potential for increasing the share of renewable energy in the end-use sectors, with specific challenges for renewables in buildings, industry and transport.

Buildings have the highest share of renewable energy according to REmap. This consists mainly of bioenergy. Solar thermal for water heating and cooling has great potential as well, but limited awareness and a lack of design standards are holding back the market.

- Requirements for solar water heaters could be included in building codes, in line with the experience of many other countries. Demonstration projects for nascent solar cooling technologies should be considered.

Industry has a high renewable energy potential through the additional use of bioenergy and solar thermal for process heat. Limited awareness of the potential for solar collectors to supply heat for industrial processes and the intermittent supply of energy pose barriers, as well as space limitations that might be an issue for existing plants.

- The potential for solar thermal energy to substitute for petroleum products should be highlighted, for example through local demonstration projects. Solar thermal storage capacity and/or hybrid solutions in the design and construction of new industrial plants should be considered.

In **transport** the focus for renewable energy is on liquid biofuels, while electric vehicles remain largely unaddressed. A lack of infrastructure and regulatory frameworks is holding back the potential that REmap has identified for electric vehicles and electric two- and three-wheelers.

- Infrastructure investments, such as charging infrastructure at large parking lots in cities, should be combined with support policies (*e.g.*, tax exemptions) to expand the market for electric vehicles and electric two- and three-wheelers. The local vehicle manufacturing base should be involved early on to kick-start the market and maximise localisation benefits.

Finally, challenges on both the supply and demand side related to **bioenergy** across sectors and applications need to be addressed. Ambitious mandates for liquid biofuel blending come with sustainability-of-supply concerns, and yield improvements and use of degraded lands alone might not be enough to meet the targets. For the use of residues and waste, challenges include the seasonality of supply, high transportation cost, financial viability and lack of grids to interconnect projects, and competition with other uses. The potential for the use of modern cook stoves using solid biomass and ethanol instead of traditional uses of bioenergy for cooking was also identified, but limited awareness and relatively high upfront investments required pose barriers for their uptake.

- A comprehensive bioenergy programme for Indonesia that includes relevant stakeholders on the supply and demand sides is recommended. The objective should be to maximise the sustainable use of Indonesia's bioenergy resource through the development of gradually increasing targets across sectors. Innovative approaches and technologies on both the supply side and demand side should be included, while the environmental, social and economic sustainability of bioenergy use in Indonesia should be safeguarded. The efforts of the Indonesia Clean Stove Initiative and the Indonesia Domestic Biogas Programme should be expanded to advance the dissemination of modern cook stoves based on bioenergy.

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ANNEXES

Annex 1: Summary of results

		Unit	2010	2014	Reference Case 2030	REmap 2030
TFEC	Total final energy consumption – TFEC	PJ	6 031	7 317	13 064	12 726
	Total renewable energy consumption (incl. electricity and direct uses; incl. traditional biomass)	PJ	1 835	2 233	2 724	2 839
	Total renewable energy consumption (incl. electricity and direct uses; excl. traditional biomass)	PJ	376	669	2 169	2 839
Renewable energy share	Share of renewable energy in final energy consumption of direct uses (excl. electricity; incl. traditional biomass)	%	32%	32%	19%	19%
	Share of renewable energy in final energy consumption of direct uses (excl. electricity; excl. traditional biomass)	%	5%	9%	14%	19%
	Share of total renewable energy use (incl. traditional biomass) in TFEC	%	30%	31%	21%	23%
	Share of total renewable energy use (excl. traditional biomass) in TFEC	%	6%	9%	17%	23%

Annex 2: Technology cost and performance data assumptions

Renewable Energy Technologies, in 2030						
	Capacity Factor	Lifetime	Reference capacity or annual mileage	Overnight capital cost	O&M costs	Conversion efficiency
INDUSTRY SECTOR	**(%)**	**(years)**	**(kW)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**
Solar thermal	14	25	500	300	9.84	100
Biomass boilers	85	25	500	580	14.5	88
Biomass gasification	80	25	500	2 000	50	85
Bioenergy CHP (electricity part)	50	25	10 000	231	5.775	79.6
BUILDINGS SECTOR	**(%)**	**(years)**	**(kW)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**
Water heating: Solar (thermosiphon)	12	20	82	150	3.8	100
Space Cooling: Solar	12	20	5.0	1 350	33.8	85
Cooking biogas (from AD)	10	25	1.5	39	1.0	50
Cooking biomass (solid)	10	20	2.0	15	0.4	40
Cooking bioethanol	10	20	1.5	10	0.3	50
TRANSPORT SECTOR	**(%)**	**(years)**	**(passenger-km/ yr/vehicle)**	**(USD / vehicle)**	**(USD/ vehicle/ yr)**	**(MJ/ passenger-km)**
First generation bioethanol (passenger road vehicles)	N/A	12	15 000	28 000	2 800	1.6
Second generation bioethanol (passenger road vehicles)	N/A	12	15 000	28 000	2 800	1.6
Biodiesel (passenger road vehicles)	N/A	12	15 000	30 000	3 000	1.5
Battery electric (passenger road vehicles)	N/A	12	15 000	32 000	2 880	0.0
Battery electric (public road vehicles)	N/A	15	60 000	48 500	13 000	0.0
Battery Electric Two-wheeler (passenger road)	N/A	8	5 000	4 100	400	0.0
POWER SECTOR	**(%)**	**(years)**	**(kW)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**
Hydro (Small)	65	40	0.1	2 500	56	100
Hydro (Large)	39	60	100	1 500	30	100
Wind onshore	25	30	100	1 500	60	100
Solar PV (Rooftop)	16	30	0.1	1 400	14	100
Solar PV (Utility)	16	30	1.0	1 000	10	100
Biomass power	66	25	50	2 750	30	25
Geothermal	80	50	25	2 500	124	10
Tide, wave, ocean	40	25	5.0	3 500	67	100

Source: IRENA analysis

Annex 3: Energy price assumptions

Commodity name	Unit	2030 government prices (excluding taxes and subsidies)
Steam coal	USD/GJ	3.5
Electricity household	USD/kWh	0.11
Electricity industry	USD/kWh	0.12
Natural gas household	USD/GJ	10.9
Natural gas industry	USD/GJ	10.9
Petroleum products for heating / electricity	USD/GJ	35.0
Gasoline for transport	USD/GJ	34.2
Diesel for transport	USD/GJ	19.8
Conventional liquid biofuels for transport	USD/GJ	20.2
Advanced liquid biofuels for transport	USD/GJ	34.8
Biomethane	USD/GJ	30.5
Primary bioenergy	USD/GJ	11.7
Bioenergy residues	USD/GJ	3.4
Traditional uses of bioenergy	USD/GJ	3.2
Waste	USD/GJ	1.1

Source: IRENA analysis

Annex 4: Renewable energy resource maps

Figure 34: Global wind dataset – 5 kilometre onshore wind speed at 80 metre height with units in metres per second

Source: © VAISALA Global Wind Dataset 5km onshore wind speed at 80m height, extracted from IRENA Global Atlas www.irena.org/GlobalAtlas

Figure 35: Global solar dataset – 3 kilometre with units in watts per square metre

Source: © METEOTEST; based on www.meteonorm.com, extracted from IRENA Global Atlas www.irena.org/GlobalAtlas

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