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Energy for Sustainable Development 59 (2020) 33–48 Contents lists available at ScienceDirect Energy for Sustainable Development An assessment of energy policy impacts on achieving Sustainable Development Goal 7 in Indonesia Wayan G. Santika a,b,⁎, Tania Urmee a, Yeliz Simsek a,c,d, Parisa A. Bahri a, M. Anisuzzaman a a Discipline of Engineering and Energy, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia b Department of Mechanical Engineering, Politeknik Negeri Bali, Bali, Indonesia c Department of Mechanical and Metallurgical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, Chile d UC Energy Research Center, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, Chile article info Article history: Received 20 December 2019 Revised 30 August 2020 Accepted 31 August 2020 Available online xxxx Keywords: Sustainable Development Goals Energy policy effectiveness Energy access Renewable energy Energy efficiency Indonesia abstract As countries start to implement the Sustainable Development Goals in their national development agendas, re- views of the current policy environment are necessary to ensure that the goals are achievable by 2030. The pres- ent study assesses the effectiveness of energy policy in Indonesia in supporting progress towards universal energy access, a substantial increase in renewable energy deployment, and improvement in energy efficiency. Laws and regulations related to energy were reviewed, and their contribution to achieving the energy targets of the Sustainable Development Goals in Indonesia was evaluated in terms of policy effectiveness. Results show that providing electricity for the remaining 1.1 million households living in the outermost and least devel- oped regions of the archipelago is very challenging. However, Indonesia is still on track to achieve 100% residen- tial electrification by 2030 as long as enough budget is allocated annually. Indonesia may not be able to provide access to clean cooking fuels and technology for everyone by 2030. The current policy focusing mostly on gas for cooking will be less effective in reaching the remaining households that cook with solid biomass and usually live in poverty. Similarly, the current policy scenario is not sufficient to allow enough progress to achieve the renew- able energy target. Finally, the assessment of energy efficiency policy suggests that sectoral energy use is shaped by variables and regulation not primarily intended to improve energy efficiency. © 2020 International Energy Initiative. Published by Elsevier Inc. All rights reserved. Introduction The Sustainable Development Goals (SDGs) were ratified in Septem- ber 2015. A total of 193 countries agreed to strive to achieve 169 ambi- tious targets associated with the 17 SDGs by 2030, including to eradicate poverty and hunger, provide access to basic services, promote prosper- ity, and protect the environment (UN, 2015). This 2030 global agenda for sustainable development is expected to provide a framework to in- tegrate social, economic, and environmental goals. The vital role of en- ergy as a key enabling factor in achieving the SDGs was acknowledged (McCollum et al., 2018; Nerini et al., 2018; Santika et al., 2019). It was therefore included as the seventh SDG (SDG7): to ensure access to af- fordable, reliable, sustainable, and modern energy for all. SDG7 has three main targets for 2030: universal energy access, an increase in the share of renewable energy (RE) in the world's energy consumption, and improved energy efficiency. The SDGs index has ranked the current status and progress of 156 countries, putting Sweden, Denmark, and Finland as countries with ⁎ Corresponding author at: Discipline of Engineering and Energy, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia. E-mail address: wayan.santika@murdoch.edu.au (W.G. Santika). the highest scores in 2018. None of them, however, are on track to meet all of the SDGs (Sachs et al., 2018). On a global scale, the 2018 monitoring report on SDG7 reveals that the goal will not be met by 2030 if current trends continue. For instance, under the current trajec- tory, only 92% and 73% of the global population will enjoy electricity and clean cooking fuels, respectively, by 2030 (World Bank, 2018a). It means that 8% of the global population will remain without electricity, and more than a quarter of the population will still cook with highly polluting fuels. Additionally, the RE share of final energy consumption is anticipated to be 21%, which could not be considered a substantial increase from the baseline value of 18.3% (IEA and the World Bank, 2017). Finally, the annual rate of decline of energy intensity (measuring energy efficiency) is anticipated to be 2.4% by 2030, which will miss the target of 2.6% (World Bank, 2018a). Likewise, at this stage, Indonesia seems unlikely to achieve the SDGs despite the government's efforts to incorporate most of the SDGs into its national development agendas. It was ranked 99th among 156 countries in 2018, and its performance was excellent only on SDG1 (no poverty) and SDG13 (climate action), scoring 96.3 and 89.1 (out of 100), respec- tively (Sachs et al., 2018). The poorest progress was in SDG9 (industry, innovation, and infrastructure) and SDG10 (reduced inequality), scor- ing 23.5 and 34.9, respectively. The current achievement of SDG7 in https://doi.org/10.1016/j.esd.2020.08.011 0973-0826/ Indonesia was moderate, considering its high electrification ratio coupled with low clean cooking energy access and low emission effi- ciency of the electricity generation sector (Sachs et al., 2018). Indonesia's electrification ratio was 98.3% in 2018 (Afriyadi, 2019; MEMR/DGE, 2019), and the government claimed that the population without access to clean cooking fuels was 26.8% in 2016 (BPS, 2017a). The RE share was only 8.43% in 2016 (Mulyana, 2018), which is far below the 23% target by 2025. However, energy intensity in Indonesia was 3.525 MJ/$2011 PPP GDP in 2015, which was much better than the world average energy intensity of 5.132 MJ/$2011 PPP GDP (World Bank, 2019a). In comparison with its neighbouring countries, Indonesian energy intensity is lower than that of Vietnam, Thailand, and Malaysia (5.945, 5.412, and 4.682 MJ/$2011 PPP GDP, respectively), but higher than that of the Philippines and Singapore (3.122 and 2.395 MJ/$2011 PPP GDP, respectively). Since SDG targets are interlinked (ICSU, 2017; McCollum et al., 2018; Nerini et al., 2018; Santika et al., 2019), it is hard to imagine that Indonesia will soon achieve the goal of health (SDG3), while more than 25% of its population cook with polluting solid fuels. Smoke from solid fuel combustion contributes to indoor air pollution, which is a major health risk factor (Smith & Pillarisetti, 2017). Additionally, a Chi- nese study shows a shift from solid fuels to clean fuels is determined by assets and income growth (SDG8) (Hou et al., 2018), which indicates that the segment of Indonesia's population still cooking with solid fuels may live below the poverty line (SDG1). Furthermore, ambitious upscaling of RE and a further improvement in energy efficiency are needed to ensure that the country is on track with the 2 °C pathway (SDG13) (McCollum et al., 2018). Energy policy is formulated to attain certain goals. Furthermore, given that support policies are usually associated with high financial costs, the evaluation of energy policy performance is necessary to identify potential inefficiencies and ineffectiveness in its application (IRENA, 2012). Clearly, effective energy policy is essential to meet the SDG7 targets. This study examines the status of the SDG7 targets in Indonesia, analyses their interactions with energy policy, and evaluates the effec- tiveness of the policy in meeting the targets. It seeks to answer the fol- lowing questions: (i) which energy policy is linked to SDG7, (ii) how this energy policy interacts with SDG7, and (iii) how effective it is in achieving the SDG7 targets. This analysis offers a careful screening of energy-related laws and regulations in Indonesia and evaluates their ef- fectiveness in supporting the achievement of the three targets of SDG7. This analysis and the methodology used are expected to serve as an ex- ample and can be applied to other countries. Overview of the Indonesian energy sector Indonesia is the world's largest archipelagic country and is located in Southeast Asia between the Indian and Pacific Oceans. This tropical country was home to almost 264 million inhabitants in 2018 (World Bank, 2019b), making it the 4th most populous country in the world. With a GDP of 3243 billion $ (PPP) in 2017, it was ranked the 8th largest economy under the PPP valuation (World Bank, 2018b). Over 35% of the total energy demand in Southeast Asian countries was from Indonesia (IEA, 2017a). The total final energy consumption (TFEC) was 5.5 billion GJ in 2018, of which the transportation and industrial sec- tors used 46.6% and 29.9% shares of the TFEC, respectively (MEMR, 2019). Fig. 1 shows that oil share in the total commercial primary energy supply was the highest (38.81%), followed by coal (32.97%), and natural gas (19.67%), leaving only an 8.55% share for renewables (MEMR, 2019). Indonesia is blessed with energy resources (Dutu, 2016; Gunningham, 2013; Mujiyanto & Tiess, 2013). However, if the current trends of production and consumption continue and no new reserves are found and exploited, Indonesia will run out of coal, oil, and natural gas in 72, 11, and 32 years, respectively (see Table 1). The total RE po- tential in Indonesia is about 443.2 GW, which is sourced from solar (207.9 GW), hydropower (94.5 GW), wind (60.6 GW), bioenergy (32.65 GW), geothermal (29.5 GW), and ocean (18 GW); unfortunately in 2015, less than 2% of these resources were utilized (MEMR, 2017a). The decline in oil reserves in Indonesia and its status as a net oil importing country since 2004 (MEMR, 2017a) have opened up new op- portunities for renewable energy development. For instance, the Minis- try of Energy and Mineral Resources (MEMR) Regulation 32/2008 has imposed mandatory biodiesel use in transport, industrial, and electricity generation sectors since 2008. Renewable energy has great prospects for development in the future of Indonesia. Methodology Policy screening and analysis were conducted to examine the status of SDG7 targets and their interactions with energy policy in Indonesia. The analysis also evaluated the effectiveness of the policy in meeting the targets. Policy screening process The screening process was based on the list of Indonesian energy- related policies provided by the Ministry of Energy and Mineral Re- sources (MEMR) in forms of laws and regulations.1 The policies were then grouped and reviewed based on their hierarchy, from laws, gov- ernmental regulations, presidential regulations (including decrees, and instructions), to MEMR regulations. MEMR decrees, regulations of the directorate generals under the MEMR, and those passed by minis- tries other than the MEMR were omitted. A qualitative content analysis was then conducted to provide a list of energy policies related to SDG7. The list was compiled by firstly examin- ing the titles of the laws and regulations for their potential links to elec- tricity access, clean cooking fuels and technology access, RE, and energy efficiency. Those with potential links to SDG7 were downloaded for fur- ther screening. The texts were further analysed to see if their contents regulate any of the above areas of interest, either alone or in combination. Policy analysis The literature suggests four criteria with which energy policy can be assessed, i.e., effectiveness, efficiency, equity, and institutional feasibil- ity (IRENA, 2012; IRENA, 2014). In this study, energy policy was analysed solely on its effectiveness in meeting SDG7. Table 2 shows in- dicators of effectiveness chosen in this study. The Policy Effectiveness Index (PEI) reflects the performance of RE policy in stimulating RE development in a particular year and is calcu- lated as additional RE production in that year divided by the remaining target (IEA, 2008), or PEI ¼ TPtt,,n20−25P−t,nP−t,1n ð1Þ where Pt,n is RE production of technology t for the year n, and Tt,2025 is the target of RE technology t by 2025. In the case of Indonesia, the 2025 National Energy Plan targets (locally known as RUEN) were chosen. Finally, data were plotted in time-series graphs, and changes in graphs' curve directions were observed and associated with energy pol- icy issued prior to the changes. Data collection Data were gathered mostly from: (1) government reports, includ- ing the Handbook of Energy & Economic Statistics of Indonesia (MEMR, 2012; MEMR, 2019), Statistics of New and Renewable Energy and Energy Conservation (MEMR, 2016), the National Energy 1 The list is available at https://jdih.esdm.go.id/index.php/web/result?q= 0.03% 1.94% 1.78% 0.02% 2.03% 0.01% 2.74% Oil Coal Natural Gas Hydropower 19.67% 38.81% Geothermal Solar Wind Other Renewables Biofuel Biogas 32.97% Fig. 1.

Indonesia's primary energy mix in 2018. Traditional use of biomass is excluded. Other renewables include biomass, biogas, and waste generated power plants. Data source: (MEMR, 2019). General Plan (MEMR, 2017a), the Annual Performance Report (MEMR/DGE, 2018), Statistics of Electricity (MEMR, 2018a), and PLN's Electricity Power Supply Business Plan (PLN, 2019); (2) the BPS-Statistics Indonesia, including the National Socio-economic Survey (BPS, 2018a), Indonesia's population profiles based on SUPAS 2015 (BPS, 2016a), and Welfare Statistics (BPS, 2019); and (3) the World Bank database (World Bank, 2019a; World Bank, 2019c). These data are publicly accessible. Policies linked to SDG7 There were 932 laws and regulations listed in the MEMR webpage (Table 3). The oldest and newest regulations on the list were the Mining Law 11/1967 and MEMR Reg. 1/2019, respectively. Most of them were excluded during the initial title screening process, leaving only 118 laws and regulations for further analysis. Seventy-three laws and regu- lations were found to relate to SDG7 targets and are listed as supple- mentary material (Appendices, Table A1). Table 4 shows that five regulations solely address the electricity ac- cess (EA) target, while 5, 29, and 20 address clean cooking fuels and technology access (CC), renewable energy (RE), and energy efficiency Table 1 Fossil energy potential in Indonesia (2018). Data source: (MEMR, 2019). Fuels Proven reservesa Production Years left Coalb Oil Natural gas 39.9 billion tons 3.15 billion barrels 96.06 trillion SCF 557.77 million tons 281.83 million barrels 2.9968 trillion SCF 72 11 32 a According to the Ministry of Energy and Mineral Resources, proven reserves are those scientifically estimated with a high degree of certainty and ready to be commercially ex- tracted (MEMR, 2017a). b Coal reserve includes a mix of proven and inferred reserves. (EE) targets, respectively. Five others regulate both electricity access and renewable energy (EA-RE) targets, while EA-EE, CC-EE, and RE-EE combined targets have one policy each. Two others simultaneously ad- dress EA-RE-EE targets. Finally, four regulations are related to all SDG7 targets. Overall, Indonesia has passed more laws and regulations on re- newable energy and energy efficiency targets with 41 and 29 laws and Table 2 SDG7 indicators and reasons for selection. Indicators Reasons for choosing the indicators The current electrification ratio compared to the 100% target Based on SDG Indicator 7.1.1. Proportion of population with access to electricity The total number of households without Based on SDG Indicator 7.1.2. clean cooking fuels and technology Proportion of population with primary compared to the target of all reliance on clean fuels and technology households with access The modern RE share in the total Based on SDG Indicator 7.2.1. primary energy supply compared to Renewable energy share in the total the national target final energy consumption The actual power capacity from Indonesia sets a target for power renewables compared to the national capacity target Annual power capacity from It is a way of assessing policy hydropower, geothermal bioenergy, effectiveness using the policy wind, and solar, and the annual effectiveness index (PEI), as suggested production of biofuel by the IEA (IEA, 2008). Indonesia sets targets for those energy sources. The installed capacity of different RE It gives an insight about policy technologies by the independent effectiveness in attracting investments power providers (IPPs) and private power utilities Sectoral final energy consumption Energy policy shapes energy The national energy intensity compared to the global energy intensity target consumption patterns Based on SDG Indicator 7.3.1. Energy intensity measured in terms of primary energy and GDP Table 3 Table 5 Results of the policy screening process. SDGs and national targets. Policies Listed Title screening Content analysis Targets SDGs National (MEMR, Laws 37 7 5 2017a) Governmental regulations 134 11 7 Access to electricity 100% by 2030 100% by 2020 Presidential regulations 114 32 17 Access to clean 100% by 2030 85% access to gas for Presidential decrees 111 10 0 cooking fuels and cooking by 2015 Presidential instructions 36 5 4 technology MEMR regulations 500 53 40 Renewable energy Increase substantially by 2030 23% by 2025 and 31% Total 932 118 73 share by 2050 Energy efficiency 2.6% reduction in energy intensity of 1% reduction in final GDP, annually (IEA and the World energy intensity, Bank, 2017) annually regulations, respectively, than those on electricity access and clean cooking targets (17 and 10 laws and regulations, respectively). Policy analysis The effectiveness of energy policy in supporting the progress to- wards SDG7 is analysed by benchmarking the current national improve- ment in energy access, renewable energy share, and energy efficiency against the targets of SDG7. Since the renewable energy target lacks a precise number, the national target is applied. Table 5 shows compari- sons between SDG7 and national targets. The Indonesian electricity ac- cess target is more ambitious than the global electricity access target. Indonesia, however, has missed the target of 85% access to gas for cooking, and its universal access to clean cooking energy is unspecified by 2030. On the other hand, the renewable energy share targets of Indonesia have been clearly stated while the global target lacks a precise number. Finally, the national energy efficiency target is not as ambitious as the global one. Energy access Target 7.1 of the SDGs calls for universal access to affordable, reliable, and modern energy services. This target was interpreted as achieving a 100% electrification ratio and 100% access to clean fuels and technology for cooking. The interpretation follows the multi-tier framework of en- ergy access proposed by the World Bank, International Energy Agency (IEA), and the UN's Sustainable Energy for All initiative (Bhatia & Angelou, 2015; IEA and the World Bank, 2014). They argue that provid- ing access to electricity for all is a continuous endeavour. It starts from without access (Tier 0), to access to a daily minimum of 3 watts per household for a minimum of 4 h without considering its reliability and affordability (Tier 1), to access of at least 2 kW power capacity, available for a minimum of 23 h a day (Tier 5). Tier 5 access allows only 2 h of dis- ruption a week (reliable) and an electricity expenditure of less than 5% of household income for average use of 365 kWh/year (affordable) (Bhatia & Angelou, 2015). However, electricity access data segregated under the multi-tier framework are not readily available for developing countries, and, to the authors' knowledge, only Rwanda, Ethiopia, and Cambodia have the data (World Bank, 2018a; World Bank, 2018c; World Bank, 2018d; World Bank, 2018e). In the meantime, all households with access to electricity, from Tier 1 to Tier 5, are taken into consideration. Therefore, even a household with a simple stand- alone PV system (Tier 1) is taken into consideration and classified as having access to electricity. Electricity access Fig. B1 (see Appendices) presents a flow diagram of the effective pol- icies on electricity access. It shows the structure of laws, regulations, and Table 4 Summary of SDG7 related energy policies for Indonesia. the players related to policies on electricity access. The arrows indicate that the laws and regulations which are higher in hierarchy influence or regulate those pointed by the arrows. This study found that at least seven regulations effectively improved electricity access. In general, the progress on electrification programs is promising. The 2008–2027 General Plan of National Electricity (RUKN 2008–2027) set an electrification ratio target of 93% by 2025, and subsequent plans have set more ambitious targets. RUKN 2015–2034 and the 2017 RUEN set targets of 99.99% by 2021 and 100% by 2020, respectively. The challenging nature of providing infrastructure in an archipelagic country, however, means that more than 2000 rural villages are esti- mated to be without electricity by the end of 2019 under a business as usual scenario (MEMR/DGE, 2018). Fig. 2 shows households with elec- tricity relative to the total number of households. The number of houses with electricity increased significantly from 2001 to 2018, reducing the percentage of houses without electricity. From 2001 to 2006, more than 1 million new connections were added annually, increasing to 1.6 mil- lion houses on average every year during the 2007–2010 period. Gov- ernmental Regulation (GR) 3/2005 (concerning electricity provision and use), the fast track program (FTP) 1 of coal power plant develop- ment (Presidential Regulation 71/2006), Energy Law 30/2007, and Fi- nance Ministerial (FM) Regulation 111/2007 contributed to this improvement. FM Regulation 111/2007 ensured that the government covered the difference between the state electricity company's (PLN) rural electricity production costs and the tariff plus a margin. It gave PLN an incentive to supply electricity to more houses. The amount of household electrification achieved between 2011 and 2017 was even more significant. On average, almost 3.5 million more houses were supplied with electricity each year. The electrification ratio rose remarkably to 98.3% in 2018, surpassing the 97.5% target (MEMR, 2018a; MEMR/DGE, 2019). The policy responsible for this achievement relates to the decision in 2011 to finance rural electrifica- tion programs under a specifically allocated budget (locally known as DAK). DAK is the state budget assigned to regional governments for car- rying out national priority programs. The state budget allocated to PLN for electrification programs increased more than fivefold, from only IDR 571 billion in 2010 to IDR 2.93 trillion in 2011 (Nugroho, 2012). As a result, almost 5.6 million more houses were connected with elec- tricity in that year alone, and the electrification ratio grew considerably from 67.15% to 72.95% (MEMR, 2018a). FTP 1 continued to contribute to the improvement together with fast track program 2 (FTP 2). A more re- cent announcement from the ministry claimed that the electrification ratio reached 98.3% in 2018 (Afriyadi, 2019). Fig. 2 indicates that, if the current progress is maintained under the current policy scenario, 100% electricity access is achievable by 2020. Targets EA CC RE EE EA-CC EA-RE EA-EE CC-RE CC-EE RE-EE EA-CC-RE EA-CC-EE EA-RE-EE EA-CC-RE-EE Tot-al Regulations 5 5 29 20 0 5 1 0 1 1 0 0 2 4 73 80 70 Million households 60 50 40 30 20 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 Total households Households with electricity Fig. 2. Electricity access in Indonesia. Data source: (BPS, 2018b; MEMR, 2008; MEMR, 2018a; MEMR/DGE, 2019). Access to clean cooking fuels and technology Households without access to clean fuels for cooking are defined as those cooking with kerosene, charcoal, or fuelwood using unimproved cookstoves. We assume that families cooking with improved cookstoves (ICSs) in Indonesia are negligible as only 5500 ICSs of the 7000 stoves target were distributed by 2012 (from a pilot project under the Indonesia Clean Stove Initiative) (ASTAE, 2013; ESMAP, 2016). Overall, the successful implementation of the "Kerosene to LPG Con- version Program" substantially reduced the number of households without access from 48.49 to 17.81 million during the 2007–2016 period (calculated from (BPS, 2017a)). Households using primarily kerosene for cooking reduced dramatically from 20.25 million (36.6%) in 2007 to 2.51 million (3.8%) in 2016. During the same period, house- holds cooking mainly with fuelwood have been halved from 27.3 million to 14.3 million (reduced from 49.4% to 21.6%). It is not clear if the reduction in fuelwood use was due to the conversion program (Thoday et al., 2018). Fig. B2 presents the few laws and regulations affecting access to clean cooking and technology, and Fig. 3 shows households without ac- cess to clean cooking fuels and technology between 2007 and 2016. During this period, the percentage of households without access to clean fuels and technology decreased significantly from 87.6% to 26.8%. Between 2008 and 2009, under PR 104/2007, approximately 15.8 million and 24.2 million free LPG starter kits were distributed to households and small/micro enterprises respectively (Thoday et al., 2018), contributing to a substantial reduction from 48.5 million house- holds in 2007 to 36.7 million households in 2009 without access to clean cooking technology. From 2010 to 2015, a total of 13.6 million LPG starter kits were distributed (Thoday et al., 2018), contributing to a fur- ther reduction to 20.1 million households without access in 2015. By 2016, about 17.8 million households remained without access to clean cooking fuels and technology (BPS, 2017a). A recent national socio- economic census reveals that 17.46% of households were still without access to clean fuels and technology in 2019 (BPS, 2019). Unlike electricity, there is no policy specifically targeting the reduc- tion of fuelwood use (or solid biomass in general). A proxy target of the 2014 National Energy Policy (locally known as KEN) was to achieve an 85% share of gas use in the household sector by 2015, but almost 30% of households still cooked either with fuelwood, kerosene, or charcoal in 2015 (BPS, 2017a). The 2017 National Energy General Plan (locally known as RUEN) sets targets of 4.7 million and 1.7 million houses con- nected to natural gas pipelines and biogas digesters, respectively, by 2025 (MEMR, 2017a). A centrally controlled gas pipeline will mostly serve city houses previously consuming LPG, and in this way, biogas di- gesters may replace LPG and traditional biomass. Since there is no major program addressing solid biomass use, universal access to clean cooking energy may not be achieved by 2030, as predicted by the (dashed) trendline2 (Fig. 3). When the trendline is extended to 2030, almost 5 million households will still be left behind without access to clean cooking fuels. At this stage, it appears that Indonesia is not on track to reach universal access to clean cooking. Targeting only 1.7 million houses connected to biogas digesters will not suffice to address the issue, especially when the ministerial data (MEMR, 2017b) suggest that biomass consumption of the household sector (mostly solid) increased significantly during the 2007–2016 period. It suggests that households relying on solid biomass for cooking could be much higher than the estimation, with fuel stacking (using more than one fuel side-by-side) likely (Andadari et al., 2014; Thoday et al., 2018). Renewable energy SDGs Target 7.2 is to increase the share of renewable energy in the global energy mix substantially. Indonesia sets its target to be 23% of the total primary energy supply (TPES) by 2025. Fig. B3 shows laws and regulations strongly associated with the development of the renew- able energy share in Indonesia. The interactions between these regula- tions and the development in renewable energy are depicted in Fig. 4. 2 More information about trendlines can be found at https://support.office.com/en-us/ article/choosing-the-best-trendline-for-your-data-1bb3c9e7-0280-45b5-9ab0-d0c93161daa8 60.00 50.00 Million households 40.00 30.00 20.00 10.00 y = 53.561e-0.107x R² = 0.9859 - Fig. 3. Households without access to clean fuels for cooking and its trendline to 2030, fitted to the 2007–2016 historical data. Data source: (BPS, 2017a). The government claimed an achievement of 8.43% RE share in 2017, which increased from 4.42% in 2010 (MEMR, 2016; Mulyana, 2018). The policies responsible for this progress include Energy Law 30/2007, which obligates local and central governments to increase the utiliza- tion of local and renewable energy and encourages them to provide in- centives for renewable energy use. In 2009, the Electricity Law was passed. In agreement with the Energy Law, the Electricity Law requires that electricity generation should prioritize renewable sources. The laws were soon supported by MEMR 31/2009 and MEMR 32/ 2009, obligating PLN to buy electricity generated from small RE and geo- thermal producers, respectively, under the feed-in-tariff (FIT) mecha- nism. Presidential Regulation (PR) 61/2011, concerning the national action plan to reduce greenhouse gas emissions (RAN-GRK), also sought to provide electricity from RE and biogas digester sets in compliance with the Kyoto Protocol to the United Nations Framework Convention on Climate Change. The protocol bound its state parties to reduce green- house gas emissions, and Indonesia passed the protocol as a national law in 2004. However, progress was slow until 2012 despite the regula- tory framework development. The RE share in the energy mix only in- creased from 4.42% in 2010 to 4.52% in 2012 (MEMR, 2016). The slow rate of increase is understandable, considering that RE projects may take years to complete. In 2013, electricity consumption from RE increased by almost 9 mil- lion BOE to 60.68 million BOE (see Table 6). However, the increase was mainly due to the contribution of two large hydropower plants (603 MW total capacity) operating since the 1980s in North Sumatera, and three hydropower plants (365 MW) located in South Sulawesi. It turns out that those plants were added to the national list only in 24 22 y = 0.0636x2 + 0.0538x + 4.0918 20 R² = 0.9788 18 16 Percent 14 12 10 8 6 4 2 0 y = 3.6111e0.1044x R² = 0.9502 y = 0.626x + 3.1382 R² = 0.94 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 Fig. 4. Modern renewable energy share in the TPES and its trendlines to 2030. The blue, orange, and grey dashed lines assume polynomial, exponential, and linear trends, respectively, fitted to the 2010–2017 historical data. Data sources: (MEMR, 2016; Mulyana, 2018; Panggabean, 2017). Table 6 Primary energy use in Indonesia. Data source: (MEMR, 2016). Sources Primary energy use (Million BOE) 2010 2011 2012 2013 2014 2015 Renewable electricity Biodiesel Coal Oil Natural gas 48.18 49.77 1.26 2.03 281.40 334.14 518.41 546.64 269.94 261.71 51.68 60.68 3.79 5.93 377.89 406.37 533.83 542.95 259.46 270.13 66.73 10.44 321.60 544.80 271.38 73.50 5.18 364.62 545.73 279.63 Table 7 Targets and realization of renewable power plants (off- and on-grid) (MEMR/DGNREEC, 2017). Power plant capacity 2016 2017 (MW) Target Realization % Target Realization % Geothermal Bioenergy Hydro Solar Wind 1713.0 1643.50 2069.4 1787.9 9252.0 5334.7 92.1 91.6 11.5 2.4 95.9% 1976.0 86.4% 2291.9 57.7% 9590.0 99.5% 118.6 21.0% 19.2 1808.5 91.5% 1839.5 80.3% NA NA 96.76 81.6% NA NA 2013 (MEMR, 2013; MEMR, 2014). Biodiesel consumption also grew significantly at the same time, thanks to the MEMR 32/2008 ordering mandatory biodiesel blends ranging from 5% in the transportation sec- tor to 10% in industrial, commercial, and generation sectors by 2015. Consequently, the total RE share rose to 5.18%. Another meaningful im- provement was observed after the enactment of MEMR 25/2013. It demanded a mandatory blending of 10% biodiesel (B10) in the trans- port, industrial, and commercial sectors, and 20% in the electricity gen- eration sector, in effect since January 2014. The biodiesel consumption almost doubled from 5.93 million BOE in 2013 to 10.44 million BOE the next year (see Table 6). Electricity generated from renewables in- creased from 60.68 million to 66.73 million BOE in the same period, and coal consumption dropped significantly, which contributed to the increase in the share of RE to 6.35%. However, due to low fossil fuel prices, the biodiesel price could not compete and domestic biodiesel demand halved in 2015, slowing down RE penetration in the energy mix (GAPKI, 2017a). The govern- ment responded by passing MEMR 12/2015 and PR 61/2015. The former was the revised version of MEMR 25/2013 and increased mandatory biodiesel blending to 20% (in transport, industrial, and commercial sec- tors) and 30% (in the electricity generation sector) in January 2016. Under PR 61/2015, money collected from palm oil export levies initiated oil palm plantation funding to be used to subsidize the difference be- tween diesel and biodiesel prices. In reality, the mandatory blending im- plementation of B20 and B30 in the transport sector began in 2016 and 2020, respectively. The regulations effectively increased domestic biodiesel consumption from 0.86 million kilolitres in 2015 to 2.25 mil- lion kilolitres (2016) and 2.4 million kilolitres (2017) (GAPKI, 2017b). It helped to boost the RE share to 7.7% in 2016 and 8.43% in 2017. Fig. 4 also shows extended linear, exponential, and second-order polynomial trendlines of the renewable energy share to 2030. The most optimistic projection (the polynomial trendline) indicates that the share will be 21% by 2025. When exponential growth is assumed, it will be 19%, and the 23% target by 2025 will not be achieved if the trend continues. The minister of energy and mineral resources admitted that Indonesia might miss the target, and a target of 20% by 2025 will be more reasonable (Arvirianty, 2018). Similarly, the 2017 RUEN estimates that 45.2 GW power capacity from renewables will be necessary to reach the 23% target. However, the current power capacity from renewable energy only increased from 5.5 GW in 2012 to 7.3 GW in 2017 (see Fig. 5). If the trend con- tinues, the total power capacity will be less than 12 GW by 2025, sub- stantially lower than the RUEN target. In an attempt to achieve 23% of renewable energy share by 2025, Indonesia will depend mostly on hydropower, bioenergy, and geother- mal because of their large reserves (Maulidia et al., 2019) and their dispatchable and non-intermittent nature. Targets increased by more than 200 MW in most RE areas between 2016 and 2017, but the realisa- tion of those targets fell short in all areas (see Table 7). Geothermal and bioenergy power plant development targets were missed by 8.5% and 19.7% in 2017, respectively. Hydropower plants achieved only 57.7% of their target in 2016. Indonesia missed its renewable electricity targets 50,000 45,000 40,000 35,000 Mega Wa?s 30,000 25,000 20,000 15,000 10,000 5,000 0 y = 5612.7e0.0473x R² = 0.813 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 Actual power capacity from renewables RUEN Target Expon. (Actual power capacity from renewables) Fig. 5. Actual power capacity from renewable energy (solid blue), its exponential trendline (dashed blue), and RUEN target to 2025 (orange). Data sources: (MEMR, 2017a; MEMR, 2018a). Hydropower Geothermal Bioenergy Wind energy Solar energy Biofuel 25% Policy Effectiveness Indicators 15% 5% -5% -15% 2013 2014 2015 2016 2017 2018 Fig. 6. Policy Effectiveness Indicators (PEIs) of RE measured based on total power capacity added from 2013 to 2018. The biofuel PEI was based on biodiesel production. Constructed based on (MEMR, 2018a; MEMR/DGNREEC, 2014; MEMR/DGNREEC, 2015; MEMR/DGNREEC, 2016; MEMR/DGNREEC, 2017; MEMR/DGNREEC, 2018). even though the annual target was increased by less than 1 GW in 2017. To achieve the renewable electricity capacity of 45.2 GW by 2025, an an- nual target of at least 4.5 GW has to be met. Fig. 6 shows the policy effectiveness indicators (PEIs) of each RE. The measure is related to its annual increase in power capacity during the 2013–2018 period, except for biofuel, which was estimated based on the total volume of biodiesel production during the same period. The graph indicates that the current RE policies in Indonesia are not effective in supporting the development of hydropower and solar technology. The 6% hydropower increase in 2013 was not caused by newly added power, as has been previously explained. Geothermal energy shows progress over the last three years, but it will not be enough to meet the target. Bioenergy (electricity generated from biomass, biogas, and solid waste) showed promising progress in 2014 and 2015 only. Positive development in wind energy technology is expected in the near future. After the installation of Sidrap wind park in 2018 (75 MW), Jeneponto wind park with the power capacity of 72 MW was also installed to the Sulawesi system in early 2019 (Ayu, 2019). Other wind projects, includ- ing Sukabumi (170 MW), Lebak (150 MW), Jeneponto (175 MW), and Sidrap II (75 MW), are under negotiation with PLN (Taqwa, 2019). Fi- nally, biofuel production fluctuated, but corrective policy responses, in- cluding the mandatory biodiesel blending and oil palm plantation funding, created considerable progress towards reaching the target. Good policy instruments attract private and foreign investments (Maulidia et al., 2019; Polzin et al., 2019). These investments are repre- sented by the capacity development of renewable power plants owned by the IPPs and PPUs (see Table 8). Overall, only 745 MW of new power from RE was added between 2013 and 2017, indicating a slow influx of investments. Most of the investments flowed to geothermal energy (455 MW) and mini hydropower (177 MW). During the same period, PLN only added 31 MW of renewable power to the system (MEMR, 2018a). In contrast, almost 5000 MW of power from fossil fuels was added during the same period, of which two-thirds was generated from coal power plants (MEMR, 2018a). Similarly, PLN is planning to add 27,063 MW (48%) coal-based power plants and 12,617 MW other fossil-based power plants between 2019 and 2028 (PLN, 2019). This time, however, renewables will con- tribute about 30% of the planned installations (16,714 MW). Compared to the current achievement, this plan shows Indonesia's commitment to achieving its 23% renewable share in the national energy mix. However, intention does not always translate to the actual realisation of the plan. For example, the second fast track program (FTP2) has been initiated since 2010, and its latest plan was to install 17,458 MW power plants, including 6658 MW hydro and geothermal power plants (PLN, 2019). Still, only 755 MW power has been connected to the systems by the end of 2018. The policy most responsible for the development of RE, or the lack thereof, was the FIT mechanism. The FIT policy for geothermal energy, for example, has changed four times (under MEMR Reg. 32/2009, 2/ 2011, 22/2012, and 17/2014), offering higher prices to attract invest- ments. Similarly, the FIT policy of small hydropower has changed three times (MEMR Reg. 12/2014, 22/2014, and 19/2015) after MEMR Reg. 31/2009 and 4/2012, which regulated small and medium scales RE in general, did not attract enough investments. The regulations were finally responded positively to by the geothermal and mini-hydro energy developers, as shown in Table 8. Table 8 The capacity of renewable power plants operated by the IPPs and PPUs in Indonesia, in Megawatts. Data source: extracted from (MEMR, 2018a). Year Hydro Mini hydro Micro hydro Geothermal Wind power Solar Waste Biomass Total /biogas 2012 587.12 2013 1567.37 2014 1567.37 2015 1567.37 2016 1612.37 2017 1612.37 34.43 3.38 46.35 17.82 103.28 18.59 114.18 18.59 155.58 53.89 223.33 53.89 770.80 0.59 775.40 0.59 830.40 0.69 860.40 0.69 1065.40 0.69 1230.40 0.69 0.03 26 0.06 26 0.06 36 0.06 36 7.06 36 8.06 36 0 1422.35 0 2433.59 0 2556.39 0 2597.29 0 2930.99 13.7 3178.44 600,000,000 500,000,000 400,000,000 300,000,000 200,000,000 100,000,000 0 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 Industrial and other Transport Fig. 7. Final energy consumption of different sectors in Indonesia and related regulations to energy conservation (in BOE). Energy data are from (MEMR, 2012; MEMR, 2018b). In contrast, the tariff policy for solar photovoltaic followed a reverse auction mechanism under MEMR Reg. 17/2013. Given a ceiling price of USD 0.25/kWh (USD 0.30/kWh if the technology had 40% local content), the bidder with the lowest bid won. The high ceiling prices without a clear mechanism for loss recovery made PLN reluctant to support the policy (Horn & Sidharta, 2017). For comparison, the current electricity price in Indonesia is approximately USD 0.10/kWh. The initial regula- tion did not work well and was replaced with MEMR Reg. 19/2016. This time PLN costs were compensated, and the prices were fixed with- out auction, ranging from USD 0.145 to USD 0.25 in Java and Papua islands, respectively. We have yet to see the full impact of these policies when the MEMR changed the regulations again under MEMR Reg. 12/2017. In the same year, it was amended and replaced with MEMR Reg. 43/2017 and 50/ 2017, regulating all types of RE. The tariffs were fixed based on the re- gional and national average generation costs (locally known as BPP). On some occasions, the tariffs were set to only 85% of the BPP. Since the BPP is influenced mainly by the costs of coal-generated power plants (PPs), the renewable

PPs now must directly compete with cheap coal PPs. The low tariffs as a consequence of the regulation will reduce the profitability of a project and thus will discourage private investments (Kennedy, 2018). Energy efficiency Fig. B4 presents the structure of the laws, policies, and respective players responsible for energy efficiency related activities. One of the most significant regulations related to energy conservation in the 21st century Indonesia is policy on renewable energy development and en- ergy conservation (under MEMR Decree 2/2004) (MEMR, 2003). This regulation includes energy subsidies, standardizing energy products, regulating energy conservation and management, and prioritizing re- newable energy use. Subsequently, MEMR 31/2005 and PR 55/2005 were released and provided guidelines for increasing energy conserva- tion in commercial, industrial, and residential sectors as well as fuel price increases. Effective energy efficiency policies reduce energy consumption. Changes in energy consumption patterns were observed and associated with policies applied before the changes (see Fig. 7). MEMR 31/2005 and, in particular, PR 55/2005 on oil price controls, restricted growth in energy consumption in the transport, residential, and commercial sectors. However, higher fuel prices were responded to differently by the industrial sector. The sector reduced fuel use and replaced it with much cheaper coal (MEMR, 2010). From 2004 to 2007, oil and gas con- sumption in the industrial sector decreased from 159.79 million to 132.14 million BOE, and coal use doubled from 55.34 million to 121.9 million BOE (MEMR, 2012). Consequently, the industrial sector energy consumption rose substantially in 2007. Another significant endeavour into energy conservation was the kerosene to LPG mega-conversion program (PR 104/2007), causing res- idential and commercial sectors to reduce consumption during the 2007–2010 period.3 Unfortunately, the program had no meaningful im- pact on the transport and industrial sectors. The reduction observed in the industrial sector was mainly due to an economic slowdown and coal price increase. Economic growth dropped from 6.35% in 2007 to 4.63% in 2009 (see Table 9) while the imported coal price peaked at 324.98 USD/t in 2009 from only 131.5 USD/t in 2007 (MEMR, 2012; MEMR, 2018b). These conditions helped reduce coal consumption from 121.9 million BOE in 2007 to 82.59 million BOE in 2009, while oil and gas consumption were stagnant (MEMR, 2018b). Subsequently, GR 70/2009 was passed in November 2009. It pro- posed energy efficiency standardization and labelling, encouraged in- centives for energy conservation, and required entities consuming 6000 TOE or more energy per year to conduct mandatory energy man- agement. It was followed by the introduction of PR 61/2011 concerning the national action plan to reduce greenhouse gas emissions (RAN- GRK) and MEMR 14/2012 concerning energy management. They pro- vide more detailed procedures for the implementation of GR 70/2009. The impact on energy consumption of those regulations is unclear at this point in time. The substantial drop in industrial sector energy con- sumption in 2013–2014 is likely due to a global economic crisis hitting emerging markets, including Indonesia (Gruber, 2014; Kontan.co.id, 2013). Even now, Indonesia is still experiencing slow economic growth. It appears that economic crises have kept the industrial sector energy consumption low, so it is difficult to tell if the energy conservation pro- grams have contributed to it. In June 2013, the government significantly decreased subsidies and increased the prices of gasoline (increased 44.4% to IDR 6500) and diesel fuel (22.2% to IDR 5500) under MEMR 18/2013. In November 2014, the prices were increased further to IDR 8500 for gasoline (31%) and IDR 3 Compared to kerosene, LPG has a higher caloric value. Table 9 Indonesia GDP growth (MEMR, 2018b). Year 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 GDP 6.01 4.63 6.22 6.49 6.23 5.81 5.01 4.88 5.03 5.07 growth (%) 7500 for diesel oil (27%) under MEMR 34/2014. Less than six weeks later, the prices were corrected to IDR 7600 and IDR 7250 for gasoline and diesel oil, respectively, on 1 January 2015 (MEMR 39/2014). The new prices are still significantly higher than the 2013 ones. As a result, transportation sector energy consumption slowed down in 2013 and 2014 (as a consequence of MEMR 18/2013) and became negative in 2015 (associated with MEMR 34/2014 and 39/2014). SDG energy efficiency Target 7.3 is to double the annual global rate of energy efficiency improvement. Energy efficiency is measured using the energy intensity of GDP (SDG Indicator 7.3.1), and the target is to achieve an annual reduction in energy intensity of 2.6% by 2030 (IEA and the World Bank, 2017). Assuming the reduction increases linearly from 2.1% in 2015 to 2.6% by 2030 (IEA and the World Bank, 2017), global energy intensity will decline from 5.131 MJ/$2011 PPP GDP in 2015 (World Bank, 2019a) to 3.58 MJ/$2011 PPP GDP by 2030 (Santika et al., 2019). Interestingly, the energy intensity in Indonesia was 3.53 MJ/$2011 PPP GDP in 2015 (World Bank, 2019a), which is lower than the 2030 SDGs target. The World Bank data (World Bank, 2019a) also shows that the Indonesian energy intensity declined from 5.24 to 3.53 MJ/$2011 PPP GDP during the 2001–2015 period. The an- nual reduction in energy intensity, therefore, became 2.79% during the period, surpassing the 2.6% reduction target of the SDGs (Santika et al., 2018). This is supported by our calculation showing that final energy in- tensities in 2001 and 2015 were 3.67 and 2.49 MJ/$2011 PPP GDP, re- spectively, which give a slightly lower reduction in final energy intensity of 2.73% during the period. Lower energy intensity of GDP is associated with higher energy efficiency. The higher the percentage of the annual energy intensity reduction, the lower the energy intensity. Indonesia has, however, set a lower reduction target of 1% in final energy intensity than what has been achieved, and it is suggested it should revise it to, at least, maintain the current achievement of 2.73%. Fig. 8 compares the primary energy intensity in Indonesia with the average energy intensities of high and lower-middle-income group countries and with the average value for the whole world. The graph shows that Indonesia consumed less energy for every dollar of GDP it produced than all income group countries and the world averages. Low energy intensity of GDP does not mean that Indonesia is advanced in energy efficiency. This issue is discussed in the next section. Discussions Government Regulation 79/2014 on national energy policy sets na- tional energy targets for Indonesia (see Table 10). The first four targets are comparable to the SDG7 targets, as previously discussed. The next two targets show that the primary energy supply in 2025 is expected to increase to more than twice its 2015 supply (MEMR, 2017a). While these targets and those for power generation and electricity consumption support the energy access target of SDG7, a trade-off may exist between these targets and the energy efficiency target. Indonesia expects an ambitious reduction in oil share from 46% of the total primary energy mix in 2015 to less than 25% in 2025, and at the same time to increase its coal share in order to improve its energy secu- rity. Indonesia is an oil net importer country with vast coal resources. The oil share reduction target provides an opportunity to increase re- newable energy use, which is undermined by a growing coal consump- tion target. Finally, the natural gas share remains the same. Synergies and trade-offs also exist between SDG7 and other SDGs. For instance, poor access to energy (SDG7) keeps people in poverty (SDG1), and energy poverty is strongly associated with economic pov- erty (Pachauri et al., 2013). Poor energy access usually means a lack of access to electricity and clean energy for cooking. Fig. 9 shows an exam- ple of a synergy between electricity access and poverty reduction in Indonesia. Access to electricity has a strong negative correlation with poverty. Lack of access to clean energy also will adversely affect women more than men (SDG5) (Oparaocha & Dutta, 2011). Without ac- cess to clean energy for cooking, women will spend more time 7 6 MJ/$2011 PPP GDP 5 4 3 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 Indonesia High income Lower middle income World Fig. 8. The primary energy intensity in Indonesia. The average primary energy intensities of high and lower-middle-income groups and the world are shown for comparison. Data source: (World Bank, 2019a). Table 10 Indonesian national energy targets. 1. Electrification ratio 2. Gas for cooking access 3. Renewable energy share 4. Reduction of final energy intensity 5. Primary energy 6. Per capita primary energy 7. Power generation 8. Electricity consumption 9. Oil share 10. Coal share 11. Natural gas share 100% by 2020 85% by 2015 More than 23% and 31% by 2025 and 2050, respectively 1% annually 400 and 1000 MTOE by 2025 and 2050, respectively 1.4 and 3.2 TOE/capita by 2025 and 2050, respectively 115 and 430 GW by 2025 and 2050, respectively 2500 and 7000 kWh/cap Less than 25% and 20% by 2025 and 2050, respectively More than 30% and 25% by 2025 and 2050, respectively More than 22% and 24% by 2025 and 2050, respectively collecting solid biomass (Khandker et al., 2014), and cooking with it harms their health. In addition, a recent study estimates that the imple- mentation of SDGs in the national development agenda of Indonesia will increase energy demand (Santika et al., 2020). Electricity access The analysis shows that several policies have contributed to the ex- pansion of electricity access since 2001. The inclusion of rural electrifica- tion programs in the DAK has contributed to the increase in access to electricity and put them in the spotlight since 2011. Although our trendlines indicated this could continue, experience from other coun- tries shows that supplying electricity to the last 10% to 15% of the pop- ulation is the hardest, the slowest, and the costliest since most of these houses are more remotely located (ADB, 2016). One of the latest regulations in response to the challenge in rural electrification is Presi- dential Regulation 47/2017, requiring the provision of free solar panel systems with LED lamps (locally known as LTSHE) to people in the most remote areas of Indonesia. During 2017–2019, some 400 thousand LTSHEs were to be distributed to the most remote locations for free (Fauzia, 2018). However, in 2019 there are still 1.2 million houses (1.7%) without access to electricity. Since 2019, rural electrification programs are no longer under DAK, which indicates that the programs are not a national priority anymore. The Ministry now estimates that almost IDR 11 tril- lion (USD 758.62 million) will be needed to provide electricity for the remaining households and that the PLN's budget is only IDR 2.1 trillion (Petriella, 2020). The ADB predicts that, with the current level of funding, universal electricity access will not be achieved in Indonesia by 2020. It is therefore suggested a revised target may need to be set to 2025. Access to clean cooking fuels and technology In contrast to electricity access, significantly less attention has been paid to clean cooking fuels and technology access. The existing policies do not sufficiently respond to the SDG target. There is not a specific pol- icy to ensure zero traditional use of solid biomass for cooking, which is the dominant contributor to low clean cooking access after the kerosene to LPG conversion program successfully reduced kerosene use. Address- ing the traditional use of biomass with natural gas and biogas programs will not be enough. Natural gas usually replaces LPG in urban areas, and biogas cannot reach non-farming communities. Providing LPG starter kits to the households may not bridge the gap since household choice for cooking fuels is influenced by affordability, availability, accessibility, and acceptability of the fuels (ASTAE, 2013). Without their willingness to pay for clean fuels, especially when solid biomass is abundant, people will be reluctant to adopt a clean way of cooking. A solution could be to promote the use of improved cookstoves (ICS) for those using solid biomass for cooking by including the ICS program in the national energy plan. It can be done in a similar way to the gov- ernment provision of free LPG starter kits (under PR 104/2007) or free stand-alone solar systems (under PR 47/2017) to rural households. This will ensure all households have access to a cleaner way of cooking by 2030. Lessons learned from the Kerosene-to-LPG Conversion Pro- gram and the Indonesia Clean Stove Initiative can be used to develop more effective policy at the national level. Lesson learned from the suc- cessful kerosene-to-LPG conversion program includes the necessity for 30 10 Population below international poverty line (%) 9 25 8 20 7 6 15 5 4 10 3 5 2 1 0 0 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 Popula?on below interna?onal poverty line (%) Households without electricity access Households without electricity access (%) Fig. 9. A synergy between electricity access and poverty reduction in Indonesia. Data source: (UNDESA, 2019). strong political commitment and firm policy objectives, effective mar- keting and a good public awareness campaign, a sole credible implementing agency (Pertamina), and effective monitoring and evalu- ation (ASTAE, 2013). Rural energy programs, including electrification and clean cooking, which have been nationally prioritized and financed under the DAK since 2013, were renamed in 2016 as small and medium scale energy programs to allow for urban application. However, the programs were removed from the 2019 DAK list, indicating that the government lacks commitment to achieving universal access to clean cooking. Judging from policy development and target achievement as well as the inadequate public awareness campaign, it appears that even policymakers are unaware of the indoor air pollution hazards from solid biomass smoke. The World Bank estimates that indoor air pollution from the traditional use of biomass for cooking in Indonesia leads to about 165,000 premature deaths annually (World Bank, 2014). According to the Asia Sustainable and Alternative Energy Program (ASTAE), barriers to expanding the ICS program include a lack of a de- velopment roadmap, limited working capital for producers, and no mar- ket demand for advanced ICS (ASTAE, 2013). ASTAE also finds that traditional production models, a limited supply chain, and the lack of awareness by consumers and government on the adverse effects of in- door air pollution are some other obstacles to the expansion. To achieve the target of universal access to clean cooking fuels and technology, the MEMR will need to orchestrate all aspects of the program (from plan- ning to implementation) and encourage participation from different in- stitutions and stakeholders. Those stakeholders include public and private sectors, not-for-profit organizations, universities, international bodies, users, and the relevant ministries responsible for public health, women and children, social lives and villages, industries and enter- prises, and research. Another aspect worth mentioning is the fact that cooking with biomass is associated with poverty, and when people can afford gas, they will switch to it (Smith & Dutta, 2011). This situation cre- ates an energy dilemma between providing clean energy access (mitigating energy poverty) and promoting renewable energy (mit- igating climate change). The dilemma is common in developing countries such as Indonesia, and the government response to it is usually to relegate the renewable energy target to a peripheral role (Gunningham, 2013). It is also true in the context of electricity ac- cess, in which the government prefers cheap coal-fired electricity to renewables. The domestic pressures to provide affordable and re- liable energy access in the short term trump international commit- ments and expectations to increase the share of renewable energy in the national energy mix (Gunningham, 2013). Renewable energy In regard to the renewable energy target, the current policy is not enough to allow Indonesia to meet the target. The government may push the mandatory biodiesel blend to be more than 30% by 2025 but, overall, the transport sector consumes more gasoline than diesel fuels. For example, the share of biodiesel in the total primary energy supply was only 1.94% in 2018 (MEMR, 2019). Indonesia is reluctant to force a compulsory bioethanol blend because ethanol production may become a risk to its food security. In the electricity generation sector, significant improvement has been shown by hydropower, bioenergy, and geothermal; however, their output is not enough to meet the target, while solar and wind energy show a very low de- ployment. In the case of wind energy, it is argued that low wind speeds in the country make it unattractive for investment, but such barriers do not exist for solar energy. A study involving stakeholder interviews revealed that the current policy is not attractive for investments for the following reasons (Bridle et al., 2018): Firstly, regulatory uncertainties due to frequent policy changes increase investment risks for the developers. These uncertainties have been discussed in the previous section of this paper. Secondly, the coal industry has strong ties with the government, which, in turn, offers the industry fiscal supports (tax exemption, loan guarantees, and price supports) that keep the BPP relatively low. In this economic environment, tariffs become less attractive for renewable generation. Next, the rent-seeking behaviour in fossil fuel industries hinders RE development.4 For instance, in many rural electrification cases, electricity generation from more expensive diesel generators is preferred over cheaper renewables. The involvement of subsidiaries of PLN and Pertamina (the state-owned oil company) as diesel fuel sup- pliers allegedly creates a conflict of interests that hinder the penetration of renewable energy. Lastly, the build-own-operate-transfer (BOOT) re- quirement, in which developers should transfer the ownership of the renewable PPs to PLN after 20 years of operation, significantly reduces the incentive for investment. Another study involving a detailed inventory of coal and renewable energy subsidies demonstrates that coal subsidies are substantially larger than renewable energy subsidies (Attwood et al., 2017). The study estimates that subsidies to coal in 2014 and 2015 were worth about USD 946 million and 644 million, respectively, while subsidies to renewables were worth around USD 36 million and 133 million. Since coal generates most of the electricity in Indonesia, the cost of sub- sidies for coal-fired electricity was around 4.9 USD/GWh in 2015, slightly lower than that for renewable electricity of 5.5 USD/GWh (Attwood et al., 2017). The study also reveals that total costs per unit of renewable electricity were still higher than those of coal power gen- eration, even though renewables received higher subsidies. These total costs, however, do not reflect the true costs of generation as they do not take into account the large environmental and social costs associ- ated with carbon emissions and air pollution. These externality costs of coal-generated and renewable energy electricity are estimated at 60 and 0.2 USD/MWh, respectively (Attwood et al., 2017). If the externality cost is included, then coal will not be able to compete with renewables. Likewise, subsidies for diesel fuel, kerosene, and LPG increased signifi- cantly in 2018 as the global oil prices increased (see Fig. 10). Fossil fuel subsidies reduce the competitiveness of renewables and decrease incentives to conserve energy. As the production of first-generation bioethanol may become a risk to its food security, Indonesia needs to encourage the production of sec- ond generation bioethanol, which is made from non-food sources. In 2015, the potential of agricultural wastes for bioethanol production in Indonesia was about 11.88 billion litres, mostly from rice straws, ba- nanas, and oil palms (Susmiati, 2018). For comparison, gasoline con- sumption was 30.69 billion litres in the same year (MEMR, 2018b). Indonesia is the world's largest producer of palm oil, and its production generates a vast amount of wastes, as only 10% of the plant can be ex- tracted for oil (Chew & Bhatia, 2008). However, since the national price of gasoline is low (subsidised), justifying the use of bioethanol ex- clusively based on cost considerations will be difficult. To enable the government to reach its renewable energy targets, it needs to increase spending on second-generation bioethanol research and development and provide financial incentives for its production as it is currently only in the early phases of commercialization (UNCTAD, 2016). Kurnia et al. (Kurnia et al., 2016) suggest the development of more research on (1) efficient systems of transportation and distribu- tion to link oil palm plantation, processing plants, and users, and (2) methods for efficient, cost-effective, and profitable biofuel produc- tion from oil palm wastes with less environmental impacts. At the same time, the bioethanol blending mandate should be imposed, and a tariff should be put on cheaper, foreign first-generation bioethanol (Eggert et al., 2011). These policy initiatives will increase bioethanol production, which in turn will increase learning in second generation 4 Some middlemen, including in some cases PLN subsidiaries, who are involved in the fuel distribution allegedly make profits from their close tie with PLN, which provides power purchasing agreements in favour of gas and diesel-fired power plants (Smith & Dutta, 2011). 8.0 6.0 USD billion 4.34 4.0 2.0 - 2015 3.12 3.36 2016 2017 6.93 2018 Fig. 10. Fuel subsidies in Indonesia (assuming USD 1 equals IDR 14,000). Data sources: (Adharsyah, 2019; MoF, 2019). bioethanol. The mandatory biodiesel blending program resulted in high social acceptance and so similar would be expected from a mandatory bioethanol program. In the wind energy sector, a 75 MW wind farm in operation since 2018 in South Sulawesi proves that wind energy can attract substantial foreign investment. The electricity feed-in tariff was set at USD 0.11/ kWh in 2015 (Aldin, 2018). More recently, the developer signed another contract to increase its capacity by adding another 60–75 MW. Under MEMR Reg. 50/2017, the new tariff is set to be USD 0.07/kWh, which is 85% of the regional BPP. The developer's spokesman explained that the new tariff was still feasible since the second project does not need to invest in sea or road infrastructure to access to the site. It is not clear whether the BOOT scheme is part of this new agreement, but MEMR Reg. 50/2017 does not seem to discourage investment in wind energy. Responding to the slow deployment of solar energy, the government passed MEMR Reg. 49/2018. It allows PLN's customers to install rooftop solar panels and export excess power to the grid. However, only 65% of the costs can be claimed back. While the regulation promotes rooftop solar energy production and use, PLN had indicated an unwillingness to participate in the project as it will cause significant loss of revenue from reduced consumers' electricity bills. A PLN regional business direc- tor said that rooftop solar panels should only be installed outside Java, where electricity is scarce (Agustinus, 2018). Under the current electric- ity price, the selling price of 65% of the existing electricity tariff will pro- long the payback period for rooftop solar and discourage investment. The regulation also limits the capacity a customer can install. A house powered by 2 kW grid electricity can only have 2 kW rooftop of solar panels. Lessons learned from the mandatory biodiesel blend could also be applied to solar energy. For instance, a compulsory deployment of solar energy could be imposed on governmental offices and new commercial and industrial buildings. When a new norm of rooftop solar energy develops, the regulation can be extended to existing buildings and houses. Energy efficiency GDP represents a country's total value of production and income, and energy is consumed as an input factor for production as well as to support the average standard of living (Suehiro, 2007). Therefore, while the energy intensity of GDP can indicate the energy efficiency of both the production system and standard of living, it may mask a lower quality of life. Advanced countries usually have efficient produc- tion systems and an energy-intensive standard of living. In contrast, de- veloping nations will usually have inefficient production systems and a non-energy-intensive standard of living. It would appear that low energy intensity in Indonesia is unlikely to be the result of efficient pro- duction systems; and instead be due to a lower standard of living. Using 2004 data, Suehiro (Suehiro, 2007) found that the industrial sector en- ergy intensity in Indonesia was about 2.5 times less efficient than that of Japan, while the energy intensity of the non-industrial sector was sig- nificantly lower. The per capita electricity and cooking energy consumption measures are a proxy for living standards. In 2017, 62,543,434 households (93%) enjoyed grid electricity, consuming approximately 93,583.52 GWh of electricity (MEMR, 2018a). Hence, on average, Indonesian families con- sume about 1496 kWh, annually, which falls under Tier-4 of household electricity access. Electricity access under this category is reliable enough to power daily household appliances, including general lights, phone charger, fan, television, food processor, washing machine, and re- frigerator (without air conditioning). Household energy consumption for cooking in Indonesia is very modest. Calculations using the BPS and MEMR data (BPS, 2017a; MEMR, 2019) show that kerosene and gas (LPG and natural gas) con- sumption for cooking in 2016 was 1896 and 1774 MJ/person, respec- tively. This is very close to the minimum annual cooking energy requirement for the basic human needs of 40 kg of oil equivalence or 1675 MJ/person (Modi et al., 2005). The per-person consumption of energy for cooking indicates that the average Indonesian lives a very modest lifestyle. A study assessing energy poverty in typical rural, suburban, and urban areas in Central Java shows that 48% of the households fell into the category of extreme energy poor, and an- other 43% is considered medium energy poor (Andadari et al., 2014). Central Java is one of the provinces with the lowest electricity con- sumption per household, which was 1090.6 kWh/household, or about 981.5 MJ/person, in 2017 (Tier 3 electricity access) (MEMR, 2018a). The study used household energy consumption thresholds of 2088 and 4320 MJ/cap to define extreme and medium energy- poor households, respectively. In energy efficiency measures, assessing the policy impacts of reduc- ing national energy consumption and intensity is challenging. Different variables influence sectoral energy use in a country. In the industrial and other sectors, for example, economic performance (growth) has a sig- nificant impact on energy consumption, while low economic growth is associated with lower energy demand. In the transportation sector, fuel prices particularly appear to shape consumption as a reduction in energy consumption is noted every time energy prices increase. While in residential and commercial sectors, energy consumption is associated with fuel choices, in which cooking with LPG or natural gas is more ef- ficient than cooking with kerosene. Fig. 7 shows that the transport sector has surpassed the industrial sector as the sector that consumed the most energy in Indonesia since 2013. At the same time, the energy consumption of the com- mercial and residential sectors also increased. As Indonesian produc- tion systems follow a more energy-efficient path, people are moving to a more energy-intensive society. This claim is supported by the IEA findings, in which the residential sector energy consumption in Indonesia increased 35% from 2000 to 2015 caused by increases in population, house ownership and spatial dimensions, and average per capita device and equipment ownership (IEA, 2017b). The study also shows that 86% of the increase in passenger transport en- ergy consumption during the same period was due to a greater dis- tance travelled per passenger. At the same time, there has been an activity shift from energy-intensive manufacturing to less energy- intensive production and services (IEA, 2019). Consequently, in order to meet the required targets, more attention needs to be given to the transport, residential, and commercial sectors. Efficiency improvement efforts in these sectors may include: transpor- tation infrastructure improvements to reduce traffic congestion and in- crease access to public transport; vehicle fuel conversion from oil to gas and electricity; increasing fuel efficiency standards for large and ineffi- cient vehicles; the application of building energy efficiency standards, and promoting the adoption of more efficient LED lamps, air condi- tioners, and other appliances. Data limitation A shortcoming of the present study is that it relies mostly on gov- ernment data to analyse the achievement of the targets. Some stud- ies show that official data may be intentionally manipulated for political gains (Wallace, 2016; Zhang et al., 2019) and to generate more aid (Kerner et al., 2014). A comparison of electrification ratio data between the World Bank and the Indonesian government shows a divergence that has narrowed in the most recent figures (Fig. 11). Indonesia regularly conducts an intercensal population survey (every ten years between the census) and annual national socio-economic surveys, which collect data on household electricity and cooking fuel use (see for example (BPS, 2016a; BPS, 2018a)). Table 11 reveals that estimates of the Indonesian government are significantly higher than those of the United Nations Department of Economic and Social Affairs (UNDESA) and the World Bank. Since the government energy data are based on censuses and surveys, we are convinced that they are reliable. Conclusion Indonesia has declared its commitment to incorporate the SDGs, in- cluding the energy goal, into its national development plan, as stated in its voluntary national reviews (VNRs) on the SDGs. The electrification ratio increased dramatically from 67.15% in 2010 to 98.3% in 2018. The decision to promote rural electrification programs as nationally prioritised programs financed under the specifically allocated state bud- get (DAK) is the main policy responsible for the achievement. However, the programs have not been under DAK since 2019, which explains the small increase in the electrification ratio to only 98.89% the same year. Providing electricity access to the remaining 1.1 million households by the end of 2020 will be very challenging for Indonesia as most of them are located in the outermost and least developed regions of the country. Indonesia may need to revise its universal electricity access target to 100 94.15 94.83 90 Electrifica?on ra?o (%) 80 70 60 50 40 67.15 2010 72.95 2011 96 96.46 97.01 97.54 97.62 98.14 95.35 80.51 84.35 88.3 91.16 76.56 2012 2013 2014 2015 2016 2017 Fig. 11. Electrification ratio in Indonesia: The World Bank estimate and Indonesia's claim. Data sources: (MEMR, 2013; MEMR, 2018a; Waage et al., 2015; World Bank, 2019d). Table 11 Access to clean energy for cooking (% of population) in Indonesia, according to the Indonesian government, UNDESA, and the World Bank. Data sources: (BPS, 2015; BPS, 2016b; BPS, 2017b; UNDESA, 2019; World Bank, 2019c). 2015 2016 2017 Indonesian Government UNDESA World Bank 69.42 73.23 60 63 56.49 58.37 76.71 65 – 2025, instead of 2020, as more than five times the currently allocated budget is needed to meet the target. Access to clean cooking fuels and technology has increased signifi- cantly from 12.4% to 82.54% of total households between 2007 and 2019. However, much still needs to be done to ensure zero traditional use of biomass for cooking. The current policy, which only focuses on promotion of gas, is unlikely to be effective since household choice for cooking fuels is driven by affordability, availability, accessibility, and ac- ceptability of the fuels. In areas where clean cooking fuels are unafford- able, the willingness to pay for them is low, and solid fuels are abundant, so ICS use should be encouraged. Policy on ICS use may not fully address the SDG target of ensuring access to clean cooking fuels and technology for everyone, but in the short and medium term, it ensures more effi- cient use of biomass and improves residential indoor air quality. The ICS program can be executed in line with the distribution of free LPG starter kits and stand-alone solar systems. Furthermore, rural energy programs, which address rural electrification and clean cooking, should be reinstated and funded under DAK. Renewable energy deployment rose significantly from 4.4% to 8.43% between 2010 and 2017, but current efforts will not be enough to meet the 23% target by 2025. The mandatory biodiesel blending programs, B20 and B30, has been successfully implemented since 2016 and early 2020. However, its contribution to the primary energy mix was only 1.94% in 2018 as diesel fuel consumption is less than a quarter of the total use of crude oil and petroleum products. A similar mandatory blending policy is not enforced for bioethanol. Regulatory uncertainties and frequent policy changes discourage investment in renewable elec- tricity generation. Tariff policies change from feed-in tariffs, to reverse auction mechanisms, to fixed tariffs based on average generation costs (BPP). PLN, the utility company, is reluctant to support FIT and reverse auction policies for the loss they create due to high tariffs. In contrast, low tariffs created by the BPP mechanism discourage private invest- ments. As a result, renewable generation increases only about 0.36 GW annually, far from the annual target of 4.5 GW. Policy assessments on energy efficiency and conservation show that sectoral energy consumption is influenced mostly by variables and regu- lation not primarily intended to improve energy efficiency. Energy con- sumption in the transportation sector is shaped largely by fuel pricing policy, more efficient energy use in household and commercial sectors is associated with the cooking fuel conversion policy, while decreases in industrial and other sectors' energy demand are associated with low eco- nomic growth. The energy intensity of GDP, as a proxy for energy effi- ciency, is currently lower in Indonesia than the 2030 global target, indicating modest energy consumption per dollar of production (GDP). Indonesia's annual 1% reduction target of final energy intensity is lower than the annual 2.73% reduction the country has been achieving. How- ever, while the energy intensity of GDP tends to decrease over time, the fact that energy demand in the transport sector has surpassed that of the industrial sector, and energy use in household and commercial sectors is increasing indicates that a more energy-intensive standard of living is expected. Therefore, appropriate policy responses will be needed in these sectors. Fossil fuel energy subsidies have also hindered progress in renewable energy and energy efficiency. Gradually removing subsidies for fossil fuels is necessary if progress is to be made on these targets. Declaration of competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influ- ence the work reported in this paper.

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Appendix A. Supplementary data Supplementary data to this article can be found online at https://doi. org/10.1016/j.esd.2020.08.011.

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