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Energy 196 (2020) 117100 Contents lists available at ScienceDirect Energy journal homepage: www.elsevier.com/locate/energy Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia Wayan G. Santika a, b, *, M. Anisuzzaman a, Yeliz Simsek a, c, d, Parisa A. Bahri a, G.M. Shafiullah a, Tania Urmee a a School of Engineering and Information Technology, 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 Catolica de Chile, Vicun~a Mackenna, 4860, Macul, Santiago, Chile d UC Energy Research Center, Pontificia Universidad Catolica de Chile, Vicun~a Mackenna, 4860, Macul, Santiago, Chile article info Article history: Received 9 August 2019 Received in revised form 16 December 2019 Accepted 4 February 2020 Available online 7 February 2020 Keywords: Sustainable Development Goals Energy Energy demand Energy intensity LEAP Indonesia abstract Energy is a key enabling factor within the Sustainable Development Goals (SDGs), which include erad- icating poverty and hunger, improving human well-being, and protecting the environment. Countries intending to incorporate SDGs in their development programs should expect an increase in energy consumption, and therefore, need to review their energy planning. The objective of this paper is to anticipate the additional energy requirements of Indonesia with the implementation of SDGs compared to business as usual (BAU) and current policy (CP) scenarios. Assuming all SDG targets were to be implemented in the Indonesian national development plan, the additional energy demand for each target by 2030 was calculated. It was found that 18 out of 169 SDGs targets required additional energy in the Indonesian context. Overall, more energy will be needed to achieve those 18 SDGs targets compared to the BAU scenario. Fortunately, the full realisation of the current energy policies will cover the addi- tional energy required under the SDGs scenario. 1. Introduction In September 2015, the United Nations introduced the Sus- tainable Development Goals (SDGs) as a global plan of action for people, environment, and economy [1]. The SDGs incorporated 17 goals with 196 associated targets. They replaced the Millennium Development Goals, which expired in the same year. The SDGs are global goals achievable only through implementation in local and national development agendas [2]. Most countries have adopted the SDGs into their development agendas [3], and by 2019, 144 countries have presented their voluntary national reviews (VNRs) on SDGs at the UN's High-level Political Forum [4]. There are many studies related to individual SDG targets and their implementation, but few discuss this implementation impact on energy demand. Büyüko€zkan, Karabulut and Mukul [5], for instance, presented an integrated multi-criteria decision-making (MCDM) method to determine the most suitable renewable energy * Corresponding author. School of Engineering and Information Technology, Murdoch University, 90 South Street, Murdoch, Western Australia, 6150, Australia. E-mail address: wayan.santika@pnb.ac.id (W.G. Santika).
https://doi.org/10.1016/j.energy.2020.117100 0360-5442/ source by addressing SDG7, while Schwerhoff and Sy [6] worked on SDGs by considering how an increase in the production of renew- able energy would affect the likelihood of achieving these goals in a given amount of time. Caiado et al. [7] mention some of the prob- lems and barriers related to SDGs implementation, and dos Santos and Balestieri [8] tried to understand the relationship between a group of socioeconomic and environmental factors linked with the SDGs for some cities in Brazil. Other studies discuss energy efficiency actions in achieving SDGs, including Puig, Farrell, and Moner-Girona [9] who worked on the significance of energy efficiency enhancements to meet the SDGs. They observed that besides SDG7, which aspires to double the global rate of improvement in energy efficiency by 2030, energy efficiency improvement could also contribute to SDG2, SDG3, SDG6, and SDG8. Di Foggia [10] studied energy efficiency in the residential sector and found that energy-efficient buildings can make a sig- nificant positive contribution in achieving SDG 11 and SDG 13. Alawneh et al. [11] studied the contribution of water and energy efficiency to SDGs (SDGs 6e9, 12e13, and 15) in the residential sector in Jordan. Interlinkages and cross impacts of the SDGs are also discussed in the literature. Some studies applied a nexus approach to analyse the SDGs interactions [12e14]. This approach provides a more comprehensive explanation of the interactions, yet it also will add complexity to the analysis of the corresponding energy demand [15]. Both positive and negative links between the SDG targets and energy were found by McCollum et al. [16], and their analysis suggested that the positive interactions outweigh the negative ones. Nerini et al. [17] assessed the interactions between SDG7 (related to energy access, renewable energy,

and energy efficiency) and the other SDGs and found similar results. These studies, how- ever, did not take into account the impact of the interactions on energy demand. Recently, Santika et al. [15] mapped the linkages between 25 SDG targets and energy demand and found that additional energy is required , compared to the business-as-usual, to achieve these targets. Should the SDGs be nationally mainstreamed, higher energy demand should be anticipated, and energy planning and policy may require reconsideration. Santika et al. [18] simulated the impact of SDG7 on household sector energy demand in Indonesia and found that providing clean energy access to everyone would indeed increase demand for commercially sourced energy. Subse- quently, Santika et al. [15] estimated that 599.5 MJ/person per year would be needed to end hunger in Indonesia (Target 2.1)1. They also identified SDG targets related to energy demand and offered a method for estimating the energy intensity of each target should it be realised in a development agenda. Further study on how it would work at a country level, however, was greatly required. This paper has addressed this research gap and built on their work [15] by quantifying the additional energy requirement at the country level. In doing so, it has tried to answer the question about the full impact of the implementation of SDGs on Indonesia's national energy demand. As a part of the 193 countries ratifying the SDGs in 2015, Indonesia agreed to implement them in its national development agendas. Its 2015e2019 national medium-term development plan (locally known as RPJMN) explicitly states that Indonesia would embed the SDGs into the post-2015 national development agendas. In 2017, Indonesia released its voluntary national review (VNR) report on SDGs [19]. The report claims that Indonesia has 320 na- tional indicators to measure the level of achievement in reaching the SDGs. Some are similar to the 241 global indicators of the SDGs, and others are additional and proxy indicators [19]. Subsequently, Presidential Regulation 59/2017, passed in July 2017, provides the legal basis for the implementation of SDGs in Indonesia. The regulation provides national targets that have been matched and synchronised with the SDG targets. In fact, Indonesia is committed to becoming the world pioneer and role model in SDGs imple- mentation, as stated in its national action plan on SDGs (under the National Development Planning Ministerial Regulation 7/2018). Earlier in 2017, the Government of Indonesia (GOI) released the National Energy General Plan (locally known as RUEN). RUEN is the extension of the national energy policy, which has targets as shown in Table 1. Additionally, Indonesia's national energy outlook is annually released by the Agency for the Assessment and Application of Technology (locally known as the BPPT). However, the outlook omits the impact of the SDGs implementation on energy demand. The latest outlook, for instance, exercises only demographic and economic variables under the RUEN implementation scenarios [21]. These scenarios do not necessarily reflect the SDGs. The above discussions suggest that there is a need to estimate energy demand to meet the SDGs in Indonesia by 2030 and 1 Target 2.1 means the first target of SDG2. Table 1 Indonesian national energy policy targets [20]. Targets 2015 2020 2025 2050 Primary energy (MTOE) Primary energy (TOE/capita) Power generation (GW) Electricity consumption (kWh/capita) Energy elasticity (%) Reduction of final energy intensity (% per year) National energy mix: Renewable energy (%) Oil (%) Coal (%) Natural gas (%) Electrification ratio (%) 1 1 85 100 400 1.4 115 2500 <1 1 >23 <25 >30 >22 1000 3.2 430 7000 1 >31 <20 >25 >24 compare the results with the demand under the current energy policy (CP) scenario. In the absence of an integrated plan that ac- counts for this additional energy demand, Indonesia's ambition to achieve all SDGs by 2030 is likely to fail. In this context, this study aims at estimating the additional energy requirement under the context of full implementation of the SDGs in Indonesia and com- pares the result with those under BAU and CP scenarios. This study aims to answer the following research questions: a. What would be the national energy demand, in different sectors and by fuel, in 2030 if Indonesia achieves all of the SDGs? b. What is the gap in energy demand between the SDGs sce- nario, BAU scenario, and current energy policy scenario? c. How adequate is the current energy policy environment for meeting energy demand under the SDGs implementation? This study also provides examples of how country-level energy demand is estimated under the SDGs regime and ensures that the procedure is applicable to other countries. 2. Methods This study compared a complete implementation of SDGs sce- nario against business as usual (BAU) and current energy policy (CP) scenarios. The BAU scenario assumes no new policy will be implemented in the national development plan by 2030. In this case, the historical growth of sectoral fuel consumption was assumed to continue into the future. In contrast, the CP scenario considers all demand-side targets imposed by the RUEN. The availability of useful data directed the choice of 2015 as a baseline year and 2016 as the first year of the SDGs implementation. Fig. 1 shows the data collection and analysis steps taken in this research. The desktop study provided comprehensive information on links between SDGs and energy demand. Under the BAU scenario, data of sectoral energy demand from 2001 to 2015 was collected from the Indonesian Ministry of Energy and Mineral Resources (MEMR) reports. Next, the compound annual growth rate (CAGR) of sectoral energy consumption of each fuel was calculated [18], GF;S ¼ DDFF;;SS;;22001051 1 n ?1 (1) GF,S represented the CAGR of the energy demand of fuel F in sector S, n indicated the total years between 2001 and 2015, while DF,S,2001 and DF,S,2015 represented energy demand for fuel F in sector S in 2001 and 2015, respectively. The future energy consumption growth rates were assumed to equal GF,S, and demand of fuel F of sector S by 2030 was estimated as DF;S;2030 ¼ DF;S;2015 1 þ GF;S ? m (2) Fig. 1. Flowchart of the methodology for estimating energy demand under BAU, SDGs, and CP scenarios. where m is the total years between 2015 and 2030. An exception was made for the household and transport sectors, as the energy demand in these sectors is strongly linked to the population size. For these sectors, the energy use intensity (EI) of each fuel in 2001 and 2015 (in MJ/household for the household sector, and MJ/person for the transportation sector) was deter- mined. Next, the CAGR of energy use intensity of each fuel (GF,S) was calculated. Based on the GF,S, the EI of each fuel in 2030 was esti- mated and the future energy demand of these sectors was pro- jected based on the 2030 EIs. Under the SDGs scenario, secondary data from the body of literature was obtained of the activity levels of the SDG targets linked to energy in 2001 and 2015. The activity levels include population, GDP, and other economic and socio-demographic ac- tivities that consume energy [22]. AT,2001 and AT,2015 represented the activity level of target T in 2001 and 2015, respectively. Next, the activity level CAGR of target T (GT) was calculated as GT ¼ AT;2015 AT;2001 1 n ? 1: (3) The following step was to estimate the activity level of target T by 2030 (AT,BAU), assuming the activity level CAGR of target T in the coming years will equal GT. Therefore, AT;BAU ¼ AT;2015ð1 þ GTÞ15 (4) AT,BAU is the 2030 activity level of target T before the imple- mentation of the SDGs. The next step was to identify the 2030 national SDG targets (AT,SDGs). For example, some countries may consider 100% electrification ratio (Target 7.1) as too ambitious and difficult to achieve and set a target of 95% electricity access instead. In this case, we assumed Indonesia fully implements all of the SDG targets in its development plan. After that, the activity level gap of target T by 2030 (AT,Gap) was estimated AT;Gap ¼ AT;SDGs ? AT;BAU (5) In order to calculate the energy demand of target T (DT), the energy intensity of target T (IT) was estimated using a similar pro- cedure to that offered by Santika et al. [15]. For example, the energy intensity of providing a mobile phone for everyone (IT5. b) was calculated as IT5:b ¼ tEoPp (6) where EP and top are energy use per phone and phone operating time, respectively. Eq. (6) was solved using an energy use of 16 kJ/ phone for an operating time of 27 h [23], which gave energy in- tensity of 5.19 MJ$phone?1$year?1. Once IT was identified, DT could be determined by DT ¼ IT : AT;Gap (7) DT estimates, however, were automatically computed using the Long-range Energy Alternative Planning System (LEAP) once data such as activity levels, energy intensities, growth rates, the total energy of the base year and end year were entered into the modelling software. LEAP is an energy modelling software devel- oped at the Stockholm Environment Institute to analyse energy policy and climate change [22]. It has been used especially in developing countries for integrated resource planning and emis- sion assessment [24e28]. The Government of Indonesia also uti- lizes LEAP for the national energy projection and GHG emission assessment [29]. Other Indonesia’s energy assessments using the

LEAP model in their analyses include studies on Java-Bali power capacity expansion [30], long-term electricity planning [31], and renewable electricity for energy security and emission reduction [32]. Note that DT might be made up of different fuels and different fuel consumption patterns across sectors. For instance, ensuring adequate food for everyone to end hunger (Target 2.1) required energy for farming (the agriculture sector), food distribution (the transportation sector) and retailing (the commercial sector). These sectors use various fuels (energy sources), including electricity, gasoline, diesel fuel, and natural gas. The approach used by this study was to consult the literature for the sectoral share of DT and the fuel share of sectoral DT. Otherwise, it was assumed that the shares were directly proportional to the baseline year's sectoral share and fuel share of national demand. Next is the procedure for estimating energy demand under the CP scenario. RUEN provided a large matrix of (planned) national energy programs with targets set for 2025 and 2050. Under the current energy policy scenario, RUEN targets having an impact on energy demand were identified, and their 2030 activity level of RUEN's target R (AR,2030) was estimated based on the 2025 and 2050 RUEN targets. The next steps were similar to those under the SDGs scenario. In the following section, yearly energy demand for the three different scenarios are presented, along with an analysis of energy demand by sector and fuel. Finally, these results are discussed and followed by a conclusion. 3. Results The Ministry of Energy and Mineral Resources of Indonesia (MEMR) divides energy consumers into six sectors: Industrial, Household, Commercial, Transportation, Other, and Non-energy sectors. The other sector includes mining, fishery, and construction sub- sectors. The non-energy sector is the sector that consumes fuels without releasing their energy content, which includes lubricant oil, gas, and petrochemicals used to produce substances such as ammonia and methanol [33]. Sources of energy (referred to as fuels in the texts) vary across sectors including biomass, coal, natural gas, briquette, oil, LPG, and electricity. The present study omitted the traditional use of biomass in the household sector. 3.1. BAU scenario Table 2 provides examples of estimates in industrial sector en- ergy demand, by fuel, under the BAU scenario. The 2001e2015 consumption data were used to calculate future growth (CAGR), which, in turn, was used to estimate future consumption. The in- dustrial sector total energy consumption is estimated to be 3428.20 million GJ by 2030. The projection of the transportation sector's energy demand by 2030 under the BAU scenario using the energy intensity (EI) approach is shown in Table 3. Once the 2030 EIs were obtained, the energy consumption was determined by multiplying each EI with the 2030 projected population of 296.4051 million [36]. Sectoral energy demand estimations for 2030 under the BAU scenario are shown in Table 4. The transportation sector will consume the most energy, followed by the industry and household sectors. Overall, about 10,291.7 million GJ energy demand should be anticipated under the BAU scenario by 2030. 3.2. SDGs scenario An example of how to estimate additional energy demand under the implementation of the SDGs at the national level is provided below. Target 2.1 of the SDGs calls for zero hunger by 2030. The prevalence of undernourishment is an indicator of Target 2.1. The activity levels of Target 2.1 in 2001 and 2015 (AT,2001 and AT,2015) were 37,973,754 and 18,648,726 undernourished persons, respec- tively (see Table 5). Next, the CAGR of the undernourishment (GT) and the number of undernourished people by 2030 (AT,BAU) were calculated using Eq. (3) and Eq. (4), which gave an estimate of 8,704,728 undernourished persons by 2030 under the BAU. The target (AT,SDGs) is to reach zero undernourished people by 2030, and the undernourishment gap between the SDG target and the BAU estimate (AT,Gap) becomes |8,704,728| undernourished persons (absolute value). Consequently, addressing the gap with SDGs implementation requires energy, and according to Santika et al. [15], the energy required to provide food for the undernour- ished people in Indonesia (IT) is 599.33 MJ$person?1$year?1. Therefore, the additional energy demand (DT) as a consequence of Target 2.1 implementation in Indonesia by 2030 is approximately 5,217,004.64 GJ. Due to a lack of data for some targets, calculations based on relevant associated information were made. For instance, Target 6.3 is to improve water quality by halving the proportion of untreated wastewater by 2030. According to the 2014e2019 Indonesian

Medium-term development plan (locally known as RPJMN), wastewater treatment facilities should reach 34 million urban people by 2019. By 2030, the facilities were assumed to reach 50 million urban people. BAPPENAS et al. [36] estimated that Indo- nesia's urban population would be 187,920,833 persons (63.4%) by Table 2 Industrial sector energy demand by 2030 under the BAU scenario. Data sources: [34,35]. Year Industrial Sector (million GJ) Biomass Coal Briquette Gas Kerosene Diesel Oil Fuel Oil Other Petroleum Product LPG Electricity 2001 320.91 215.28 0.45 476.02 2015 260.67 408.38 0.29 709.89 CAGR ?0.015 0.047 ?0.031 0.029 2030 208.62 810.93 0.18 1089.31 Total consumption projection in 2030: 3428.20 million GJ 24.19 274.43 1.52 301.70 ?0.179 0.007 0.08 333.93 155.14 149.52 56.50 276.29 ?0.070 0.045 19.15 533.46 5.65 4.58 ?0.015 3.66 126.88 228.42 0.043 428.86 Table 3 Transportation sector energy demand by 2030 under the BAU scenario. Data sources: [34,35]. Transportation sector Gas Avgas Avtur Gasoline Kerosene Fuel Oil Diesel Electricity EI 2001 (MJ/cap) 3.90 0.52 EI 2015 (MJ/cap) 5.58 0.41 EI CAGR 0.02667 ?0.02215 EI 2030 (MJ/cap) 8.31 0.28 2030 Energy use (million GJ) 2.46 0.08 Total consumption projection in 2030: 4045.22 million GJ 241.90 2063.57 581.50 4071.02 0.06465 0.04973 1488.13 8430.74 441.09 2498.92 0.76 0.06 ?0.18369 0.0023 0.0006 14.48 4.30 ?0.08297 1.17 0.35 1806.02 2555.98 0.02512 3708.23 1099.14 0.81 2.85 0.09204 10.75 3.18 Table 4 Estimates of sectoral energy consumption by 2030 under the BAU scenario. Industry Household Commercial Transportation Other Non-Energy Total Million GJ 3428.20 989.89 705.95 4045.22 259.09 863.35 10,291.70 Table 5 Prevalence of undernourishment in Indonesia. Data source [37]: Year Total population Prevalence of undernourishment % Persons (AT) 2001 2015 CAGR (GT) 2030 208,647,000 255,462,000 296,405,100 18.2 7.3 2.94% 37,973,754 18,648,726 ?0.04953 8,704,728 2030, so about 137,920,833 urban people will remain without wastewater treatment facilities by 2030. Wastewater generation in urban Indonesia was about 0.12 m3$person?1$day?1 [38]. There- fore, untreated urban wastewater will be approximately 6,040,932,503 m3/year by 2030. Halving this figure means treating 3,020,466,251.46 m3/year more wastewater by 2030, which will consume more energy. Table 6 shows a summary of the procedure used to calculate the amount of extra wastewater that needs to be treated per annum by 2030. Once AT,Gap is determined, the additional energy demand as a consequence of Target 6.3 implementation can be estimated. The Table 6 An example of the improvised procedure applied to Target 6.3 Variables Amount Units Total population, 2030 Urban population 2030 Urban population, 2030 RPJMN target 2014e2019 Assumed 2030 access Urban people without access Wastewater generation Wastewater untreated Halving the untreated wastewater (AT,Gap) 296,405,100 63.4 187,920,833 34,000,000 50,000,000 137,920,833 0.12 6,040,932,503 3,020,466,251 Persons % Persons Persons Persons Persons m3person?1day?1 m3/year m3/year energy intensity of wastewater treatment in Indonesia was assumed to be 0.5 kWh/m3 considering that the intensity ranged from 0.05 to 0.15 and from 0.95 to 1.25 kWh/m3 in India and China, respectively [39,40]. The extra energy consumption will, therefore, be 1,510,233,126 kWh or 5,436,839 GJ by 2030. Table 7 summarises the results of the calculations of Indonesia's additional energy requirement under the SDGs regime by 2030. Twenty-four out of 25 SDG targets linked to energy as proposed by Santika et al. [15] were assessed (Target 1.4 about access to basic services was excluded as the achievement of other targets would contribute to it). The results reveal that 18 targets will require additional energy by 2030. Target 2.4 was omitted due to a lack of national data on land areas under sustainable agriculture, and the target also lacked a precise number making it difficult to assume a national target (Indonesia has not set one). Targets 4.3 and 17.8 were considered to be achievable under the BAU scenario; hence, no additional energy will be needed. Target 7.2, concerning the substantial increase in the renewable energy share, was assumed to transform energy sources from fossil fuel to renewables and thus affect energy supply only. The target will not change energy de- mand. Finally, Targets 7.3 and 8.1 should be calculated together, and the figure reflects the maximum allowable energy demand by 2030. This issue has been further elaborated in the discussion section. Overall, SDGs implementation will require approximately 474.72 million GJ more energy on top of the BAU scenario by 2030. Fig. 2 shows that Target 9.1 (access to quality infrastructure) will consume the most energy (about 169.41 million GJ) by 2030, fol- lowed by Target 11.2 (access to safe urban transport systems for all; 87.44 million GJ), Target 7.1 (access to clean fuels and technology for cooking; 83.23 million GJ), and Target 12.3 (food losses and waste; 76.03 million GJ). The energy demand for the other targets will be about 10 million GJ or less. Targets 5. b (equal access to mobile phones) and 13.1 (resilience to disasters) will consume the least energy (about 0.22 and 0.55 million GJ), respectively. The negative Table 7 Summary of the additional energy requirement for SDGs implementation in Indonesia. SDG Description Targets Activity levels (AT) SDGs Gap Energy Intensity, annually Additional Energy demand Data and Remarks reference (AT,Gap) (IT) Unit (GJ) 2.1 Zero hunger Undernourish 8,704,728 599.33 MJ/person 5,217,005 [15,37,41] people persons 2.3 Double small Small farmer 8,722,526 1611.99 MJ/ 14,060,598 [41e43] 2003e2013 Data farmer households households household productivity 2.4 Sustainable Land area NA e e e Data and target are not available agriculture under sustainable agriculture 3.8 Universal Persons with 4,674,884 475.63 MJ/person 2,223,495 [15,44] 2011e2015 Data healthcare access unmet needs persons for healthcare 4.1 Access to primary Elementary 1,512,505 798.34 MJ/student 1,207,487 [15,45e48] 2014e2016 Data and secondary school students students education Junior high 2,224,973 991.87 MJ/student 2,206,888 [45e48] 2014e2016 Data school students students Senior high 2,605,210 1330.56 MJ/student 3,466,388 [45e48] 2014e2016 Data school students students 4.2 Access to early Kindergarten 2,161,635 pupils 598.75 MJ/student 1,294,283 [15,45e48] 2014e2016 Data childhood students education 4.3 5.b education Equal access to Access to tertiary Students of tertiary education Persons with a 42,328,459 0 5.19 MJ/person 0 219,685 [49,50] [15,23,51] The trend shows that the 40% target of gross enrolment rate will be achieved by 2030 under the BAU 2015e2016 Data e e enabling mobile phone persons technology 6.1 Access to safe Persons with 56,148,718 92.16 MJ/person 5,174,666 [39,52e54] 2015e2017 Data drinking water drinking water persons access 6.3 Halving the Cubic meters 3,020,466,251 m3 1.8 MJ/m3 5,436,839 [36,38e40] Improvised procedure proportion of untreated untreated wastewater Wastewater 7.1 Access to Households 0 1314 MJ/ e [18,34,35,55,56] 100% of electricity access will be achieved by 2020 electricity and with electricity household clean cooking Households 12,095,286 7087.26 MJ/ 85,722,464 [18,34,35,57,58] Biomass and kerosene were replaced by LPG fuels cooking with households household LPG Households 304,519 ?8200.314 MJ/ ?2,497,151 [18,34,35,57,58] Avoided kerosene use after conversion to LPG. cooking with households household Traditional biomass use was never included in the kerosene calculation since only commercial energy was considered. 7.2 Renewable Renewable energy does not change energy demand energy share 7.3 Energy efficiency Targets 7.3 and 8.1 should be calculated together using national data, and the result should be regarded as a benchmark for maximum national 8.1 Sustainable energy consumption. See the discussion section and Santika et al. [15]. economic growth 9.1 Access to road Toll road length 3261.04 km 10 TJ/km 32,610,400 [59e61] Improvised procedure infrastructure National road 6000 km 7.5 TJ/km 45,000,000 length Provincial road 6000 km 5.4 TJ/km 32,400,000 length Sub-provincial 18,000 km 3.3 TJ/km 59,400,000 road length 9.c Access to information and communication technology Persons in areas without mobile network cover 6,372,602 persons 1702.94 MJ/user 10,852,184 [15,62,63] 2011e2014 Data 11.1 11.2 adequate housing urban slums Access to Persons with Access to Persons in 5,970,911 persons 29,640,510 864.00 2950.00 MJ/person MJ/person 5,158,867 [15,64,65] 87,439,505 [66,67] 2015e2016 Data Improvised procedure convenient public convenient transport public persons transport 11.6 Urban solid waste Urban solid 2,732,669.80 588.07 MJ/t (diesel) 1,607,014 [68,69] 2015e2016 Data waste not tonnes 432 MJ/t 1,180,513 collected (electricity) 12.3 Food losses and Total 296,405,100 256.5 MJ/cap 76,027,908 [70e72] Improvised procedure waste population persons 12.5 Waste reduction Waste recycled 5,188,000 tonnes ?1640 MJ/t ?8,508,320 [69,72e74] Improvised procedure Table 7 (continued) SDG Description Activity levels SDGs Gap Energy Intensity, Additional Data and Remarks Targets (AT) annually Energy reference

(AT,Gap) (IT) Unit demand (GJ) 13.1 17.6 Access to science Fixed Resilience to disasters Relocated persons broadband subscriptions 17.8 Access to the Persons using internet internet Total additional energy demand (GJ) 403,441 persons 1353.07 23,074,583 subscriptions 315.36 0 113.7 MJ/person 545,882 [65,75] MJ/ 7,276,800 subscription [76,77] MJ/user e [78e80] 474,723,401 Improvised procedure Improvised procedure All Indonesian will have access to the internet by 2030 Fig. 2. Additional energy demand as a consequence of SDGs implementation. value of Target 12.5 (waste reduction) indicates a potential saving of energy. 3.3. Current policy scenario Nine RUEN targets related to energy demand were identified, as shown in the second column of Table 8. Since the targets need to be achieved by 2025 and 2050, RUEN targets for 2030 were also estimated (the third column of the table). It was assumed that only targets R1 and R3 would require more energy compared to the BAU scenario. Both targets anticipate about 2.05 billion GJ more energy in 2030. The other targets would not add or reduce energy demand as they replace one energy source with another. This analysis did not consider the potential to reduce energy demand as a result of added efficiencies of the substituting energy sources. LEAP results show that the total energy demand in 2030 will be about 12.29 billion GJ, which is approximately 2.00 billion GJ higher than the BAU. The discrepancy between this figure with the total demand calculated in Table 8 is accounted for by the assumption relating to target R8. The assumption in R8 will offset the transport demand under the BAU and CP scenarios at 3.11 billion GJ by 2025. The same assumption, however, will create less demand under the CP sce- nario by 2030 (see Table 9). 3.4. Scenario comparison Fig. 3 shows the LEAP result of energy demand under the BAU, CP, and SDGs scenarios. Under the BAU scenario, energy demand will rise from 5.66 to 10.29 billion GJ between 2015 and 2030. Under the SDGs scenario, the demand will increase further from the same baseline point in 2015 to 10.76 billion GJ in 2030. The demand will increase even further to 12.30 billion GJ in 2030 under the CP scenario. These results indicate that mainstreaming the SDGs in the national development plan of Indonesia will increase national en- ergy demand. However, the full realisation of its national energy plan (RUEN) will be more than enough to anticipate the rise of energy demand under the SDGs scenario. The scenarios are also compared based on their sectoral energy demand, as shown in Fig. 4. The 2030 BAU energy demand will almost be double the base year demand. Under this scenario, the transport sector will consume the most energy by 2030, followed by industrial and household sectors. Transport sector energy de- mand will grow about 5.37% annually from 1.84 billion to 4.04 billion GJ between 2015 and 2030 (see also Table 4). The other sectors' energy demand will also increase significantly, contrib- uting to the overall energy demand of 10.29 billion GJ. Under the SDGs scenario, total energy demand will rise 4.59% above the BAU total demand to 10.76 billion GJ by 2030. This rise is Table 8 Summary of RUEN targets and additional energy requirement under the current policy scenario in Indonesia. No RUEN Targets RUEN Targets Additional Energy Remarks adjusted for 2030 demand R1 Electricity consumption: 2500 and 7000 kWh/cap 3400 kWh/cap 2036.07 million GJ Assumption: this target is proportionally shared across sectors; the share is by 2025 and 2050 equal to the baseline year share R2 Pipeline natural gas for cooking: 4.7 million 10% of total It would not add It was assumed to replace LPG households by 2025 households or reduce energy demand R3 Biogas for cooking: 1.7 million households by 2025 3.4% of total 17.03 million GJ It was assumed to replace solid biomass, which was omitted in the households household sector R4 Dimethyl ether (DME) production: 1 million ton by It replaces 15% of It would not add Assumption: mixed with LPG; 60% produced from coal, 40% from biomass 2025 (about 10% of the estimated total LPG total LPG or reduce energy consumption in 2025) consumption demand R5 Electrification ratio: 100% by 2020 e e Achieved under the BAU R6 Natural gas use in the transport sector: 282.1 552.4 MJ/cap It would not add This target supports the achievement of Target R8 mmscfd by 2025 (about 372.77 MJ/cap) or reduce energy demand R7 Electric vehicle energy use: 2.3 TWh by 2025 (about 37.8 MJ/cap It would not add This target supports the achievement of Target R8 26.55 MJ/cap) or reduce energy demand R8 Petroleum-based fuels for transport: 75.3 million 2.55 billion GJ or It would not add The gasoline and diesel energy intensity growths were assumed to kilolitres or less by 2025 (about 2.55 billion GJ). less by 2025 or reduce energy decrease to 4.45% and 2.3135% to achieve this target. 30% biodiesel and 15% Our estimate shows that it will be about 3.01 billion demand bioethanol blends by 2025 were also assumed. GJ by 2025 under the BAU R9 Biodiesel for transport: 13.9 million kL by 2025 319.67 million GJ It would not add This RUEN target was constrained by the B30 biodiesel blend target. This (524.3 million GJ) or reduce energy target supports the achievement of Target R8. demand Sum of R1 and R3 energy demand 2053.1 million GJ Table 9 LEAP estimates of transport sector energy demand under the BAU and CP scenarios (in million GJ). Target R8, which is to be achieved by 2025, combined with Targets R6, R7, and R9, requires equal demand under the BAU and CP scenarios by 2025. Those targets create a demand discrepancy between the BAU and CP scenarios in 2020 and 2030. Scenarios 2015 2020 2025 2030 BAU 1844.78 2392.82 3108.55 4045.08 Current Policy 1844.78 2402.82 3108.56 4002.50 a result of slight increases in energy demand of all sectors except the non-energy sector. Mainstreaming the SDGs in the develop- mental agenda of Indonesia will produce a small increase in sec- toral energy demand. The current policy scenario calls for 2 billion GJ more electricity by 2030 in order to reach 2.5 and 7.0 MWh/cap electricity by 2025 and 2050, respectively. The target is assumed to be distributed across sectors in proportion to the sectoral shares of electricity consumption in 2015, which is calculated from the MEMR data [33]. As a result, the energy demand of the industrial, household, and commercial sectors will increase significantly compared to BAU demand. This result suggests that the current energy policy in Indonesia anticipates higher energy demand from these sectors. Fig. 5 shows the scenario comparison of Indonesian energy demand in 2030 by fuel. Under the BAU scenario, gasoline, elec- tricity, and diesel oil will contribute most of the rise in energy demand followed by natural gas, non-energy use, and coal. Incor- porating the SDGs into the national development agendas will slightly increase the consumption of electricity, natural gas, gaso- line, diesel oil, biodiesel, and LPG. The sharp increase in the 2030 Fig. 3. LEAP results of energy demand under three different scenarios. Fig. 4. Comparison of Indonesian sectoral energy demand in 2030 under the BAU, SDGs, and CP scenarios. electricity consumption under the CP scenario is much more sig- nificant. Electricity will, therefore, be the major contributor to increased energy demand in 2030 when following the Indonesian energy plan (RUEN, see Target R1 of Table 8). The rise of electricity use under the CP scenario will be more than double that under the BAU. The rise of natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use was also notable in the CP scenario; however, it will compensate the planned decline in gasoline, diesel, and LPG use in transport and household sectors (see also Table 10). 3.5. Key modifying variables Energy demand estimates under the BAU scenario assume that future energy demand growth (CAGR) equals past growth (see Eqs. (1) and (2)). Based on the equations, the CAGR is the key variable that will modify the energy demand estimate under the BAU. Variables that are positively associated with energy demand and its growth include population and GDP [81,82]. Since GDP and its growth fluctuates, energy demand and its growth are also likely to vary. Therefore, the accuracy of demand estimates also depends on how good the CAGR is predicted. For instance, the 2030 BAU energy demand will increase by 33% to 13,687.22 million GJ if sectoral energy demand CAGRs increase by 2% (see Appendices, Table A1). Under the SDGs scenario, the key parameters for energy de- mand are SDGs activity level gaps and activity level energy in- tensities (see Fig. 1 and Eqs. (3)e(7)). If we assume zero growth of the activity level CAGR of target T, or GT ¼ 0 (see Eq. (3)), then AT;BAU ¼ AT;2015 (8) and AT;Gap ¼ AT;SDGs ? AT;2015 (9) Solving Eq. (7) for each SDG target T, we found that the energy demand estimate under the SDGs scenario will be 943.85 million GJ in 2030, more than twice the previous estimate, or about 9.17% higher than that under the BAU (see Appendices, Table A2). On the other hand, energy demand under the current policy scenario depends largely on the national energy policy and plan. Different countries will have different objectives and priorities; therefore, different demands for energy. 4. Discussion The results of this investigation reveal an expected energy de- mand of 10,291 million GJ by 2030 under the

BAU scenario. This value is very close to that estimate by Indonesia's Agency for the Assessment and Application of Technology (locally known as BPPT). According to BPPT, 10,350.2 million GJ (1780 million BOE) energy will be needed by 2030 under the BAU scenario [21]. Results also show that 474.72 million GJ more energy should be added by 2030 if Indonesia is to mainstream the SDGs in its national development programs. The final energy demand under the SDGs scenario will be about 4.59% higher than the 2030 energy demand under the BAU scenario. For comparison, final energy demand in Indonesia grew Fig. 5. Comparison of Indonesian energy demand in 2030 under the BAU, SDGs, and CP scenarios, by fuel. Table 10 Comparison of energy demand under the BAU and current policy scenarios. Fuel Type (Million GJ) 2030 BAU 2030 CP Non Energy Electricity Natural Gas Gasoline Jet Kerosene Kerosene Diesel Biodiesel Residual Fuel Oil LPG Oil Coal Hard Coal Briquettes Biogas Ethanol Biomass Avgas Dimethyl ether Bio dimethyl ether Total 863.35 1591.93 1105.83 2563.12 441.07 2.69 1513.64 168.18 22.58 458.53 533.44 810.89 0.18 e e 215.88 0.08 e e 10,291.38 863.35 3635.41 1315.51 2034.98 441.07 2.68 1155.23 495.10 22.58 343.66 533.44 810.89 0.18 17.03 347.77 215.88 0.08 36.39 24.26 12,295.91 about 3.05% annually between 2007 and 2017 [33]. Furthermore, if the current policy scenario can be realised, the anticipated demand will cover the demand needed under the SDGs scenario. Published in 2017, the RUEN, on which the Indonesian current policy environment is based, is well-developed and would easily satisfy the extra energy demand under the SDGs scenario. The additional energy demand of 474.72 million GJ under the SDGs scenario might appear modest compared to Indonesia's total energy demand (TFEC), but it is comparable to Nepal's TFEC in 2014, which was about 482.91 million GJ [83]. It will be interesting to see the impact of the SDGs implementation on energy demand in the least developed countries as the gaps between the current situation and the SDG targets are more likely to be wider. As the TFEC of these countries is relatively low, a substantial increase in energy demand (relative to the TFEC) will be necessary for them to fully implement all SDGs. Under the SDGs scenario, some estimates were negative, which indicate that the implementation of targets in the national devel- opment plan will save energy . For instance, replacing kerosene with LPG to ensure access to clean cooking fuels (Target 7.1) will save energy because cooking with LPG is more efficient than cooking with kerosene. Similarly, waste recycling programs have a net en- ergy saving potential, which will reduce overall energy demand [69,72]. Target 7.3 was to double the global rate of improvement in en- ergy efficiency. The target was translated as a 2.6% reduction in the global primary energy intensity of GDP (World EI) between 2010 and 2030 [84]. Since the World EI was 5.796 MJ/2011 PPP $ in 2010 [85], applying a 2.6% annual reduction gave a World EI of 3.422 MJ/ 2011 PPP $ by 2030. Therefore, Target 7.3 will be achieved if global energy intensity is less than or equal to 3.422 MJ/2011 PPP $ by 2030. The 2030 world GDP was estimated using 2001 and 2015 per capita GDP data provided by the World Bank [86], which had a GDP CAGR of 2.48% between 2001 and 2015. If this per capita global GDP growth is sustained by 2030 (i.e., Target 8.1 is achieved), the global primary energy consumption will be 73,083 MJ/cap by 2030. Table 11 provides the quantification summary of Targets 7.3 and 8.1. Table 11 Global quantification of Targets 7.3 and 8.1 Variables Amounts Units 2010 World EI Target 7.3 (CAGR) 2030 World EI 2001 World GDP 2015 World GDP World GDP CAGR 2030 World GDP (assuming the CAGR is maintained) 2030 Primary energy use 5.796 ?0.026 3.4222 10,504 14,795 0.02477 21,355 73,083 MJ/2011 PPP $ MJ/2011 PPP $ 2011 PPP $/cap 2011 PPP $/cap 2011 PPP $/cap MJ/cap This annual primary energy use of 73,083 MJ/cap should be considered a new target designated especially for high-income countries in order to reduce energy inequality and CO2 emissions. For comparison, the average primary energy use in high-income countries was 4605.54 tonnes of oil equivalent per capita (or 192,825 MJ/cap) in 2015 [87]. In contrast, energy use was only 27,059 MJ/cap in the lower-middle-income countries in 2014. Pri- mary energy consumption of as low as 60,000 MJ/cap has been associated with a very high human development index [88]. In the Indonesian energy context, the primary energy intensity of GDP was 3.525 MJ/2011 PPP $ in 2015 [85], and reaching the global target of 3.422 MJ/2011 PPP $ by 2030 will not be difficult, especially when the energy intensity annual growth of ?2.79% between 2001 and 2015 is to be maintained by 2030 (calculation based on the World Bank data). Table 12 provides the key variables required to quantify energy demand in Indonesia by 2030 under the SDG Targets 7.3 and 8.1. The GDP data of the World Bank [86] were used to calculate the CAGR of the GDP between 2001 and 2015. If the same economic growth is sustained by 2030 (Target 8.1), the 2030 GDP will be about 18,850 2011 PPP $/cap. Multiplying this value by the 2030 primary energy intensity (2030 EI) gave a total primary energy supply (2030 TPES) of 64,505 MJ/cap which is less than the 73,083 MJ/cap benchmark previously discussed. If the population reaches 296.4 million by 2030 [36], the TPES will be 19,120 million GJ by 2030. Assuming 72% TPES to total final energy consumption (TFEC) conversion efficiency by 2030 [18], it was found that the energy demand by 2030 (2030 TFEC) will be about 13,766 million GJ. In other words, if Targets 7.3 and 8.1 are achieved by 2030, the TPES will be no more than 19,120 million GJ, and the TFEC will be about 13,766 million GJ or less, given that the TPES to TFEC ratio of 72% is also achieved. For comparison, total energy demand under the current policy scenario will be 12.30 billion GJ in 2030, which is equivalent to the primary energy supply of 57,616 MJ/cap or 3.057 MJ/2011 PPP $ of GDP. Under the current policy scenario (RUEN), Indonesia will consume less energy per capita compared to the world average in 2030. Indonesian production systems will also use less energy per Table 12 Quantification of targets 7.3 and 8.1 in Indonesia. Variables Amount Units 2001 GDP 2015 GDP CAGR of GDP 2030 GDP (assuming the CAGR is maintained) 2030 EI (Target 7.3) 2030 TPES 2030 TPES Assumed TPES to TFEC conversion ratio 2030 TFEC 5934 2011 PPP $/cap 10,367 2011 PPP $/cap 4.066 % 18,850 2011 PPP $/cap 3.422 MJ/2011 PPP $ 64,505 MJ/cap 19,120 Million GJ 72 % 13,766 Million GJ dollar it produces compared to the global economy. The ambitious RUEN target to boost electricity consumption to 2500 and 7000 kWh/cap by 2025 and 2050, respectively, will increase pri- mary energy consumption in 2030 from 48,225 MJ/cap (under the BAU) to 57,616 MJ/cap. Table 13 summaries the estimated energy demand under different scenarios and benchmarks. Finally, RUEN targets related to energy demand (identified in Table 8) reflect Indonesia’s commitment to provide access to elec- tricity and clean cooking fuel for everyone (SDG Target 7.1) and to improve energy efficiency (Target 7.3). The renewable energy target (Target 7.2) is beyond the scope of the present study as renewable energy is related to the supply side of energy and does not change energy demand. It is anticipated that electricity access will reach everyone by 2020 under the BAU. The 100% clean cooking access, however, is more likely to be missed by 2030 under the RUEN. The calculations done in this study using World Bank data [89] suggests that more than 50 million people (17% of the population) will still be without access to clean cooking fuels and technology by 2030 (those mostly cooking with solid biomass). Providing urban households with pipeline natural gas will mostly replace LPG use, which is also a clean fuel. Biogas for cooking might be a solution, but the target is only 3.4% of the population, and the program cannot reach non-farming communities. Programs that directly address solid biomass use should also be introduced. For instance, programs to replace traditional stoves with improved cookstoves (ICS) could be implemented [90]. Energy efficiency measures under RUEN are represented mostly by fuel conversion programs which have more efficient fuels than the replaced ones (see targets R2, R3, R6, and R7 of Table 8). Target R8 shows Indonesia’s commitment to reduce the use of petroleum- based fuels with either renewable energy or natural gas. RUEN offers many more programs and activities related to energy effi- ciency, but they lack precise numbers (difficult to quantify the targets to energy demand). For example, there are programs enforcing mandatory energy management for buildings and in- dustries consuming 6000 tonnes of oil equivalent or more, sup- porting the implementation of ISO 50001 on energy management, and promoting the use of efficient power plant technology. If these programs are fully implemented, a further reduction in energy demand is possible. 4.1. Research limitations and further study The scope of SDGs is very broad, from ending poverty and hunger, providing universal access to healthcare, education, water, and energy to delivering equality, good infrastructure, healthy environment, peace, justice, and partnerships. The SDGs are also, directly and indirectly, interlinked as a network of goals and targets [14]. These complex interactions of targets make the corresponding energy demand more difficult to quantify [15]. In the present study, only the direct first-degree interactions of the SDGs and energy Table 13 Summary of primary and final energy demand under different scenarios and benchmarks. Scenarios and benchmarks Primary energy demand Energy demand in 2030 (MJ/cap) in 2030 (billion GJ) BAU SDGs Current policy Minimum energy associated with a very high human development index National energy use if Targets 7.3 and 8.1 achieved nationally Global energy use as suggested under Targets 7.3 and 8.1 48,225 10.29 50,449 10.76 57,616 12.30 60,000 12.80 64,505 13.77 73,083 e demand are calculated. It does not take into consideration second- degree interactions. It should be noted that energy demand also interacts with the energy goal (SDG 7), but energy demand, per se, is not SDG 7. Some of the SDG targets may overlap, and, in some cases, there are second and third-degree interactions between the target and energy de- mand, all of which add complexity to the calculation. For example, halving food losses (Target 12.3) in Indonesia requires energy for food processing and storing. Yet, it also will save enough food to feed the undernourished people (Target 2.1). Consequently, less food must be farmed, and less energy will be needed. As is common in this kind of research, many assumptions have been made about such things as equal past and future growths of activity levels, proportionally distributed energy demand across different fuels, future population size, and GDP. Literature and historical data were consulted as the basis for these assumptions to ensure the values used were as close as possible to reality. The CAGRs were used to estimate energy demand under the BAU and SDGs scenarios. The CAGRs assumed smooth exponential growth, and growth rates in the next 15 years would be similar to those in the last 14 years. Many studies, however, have found that energy demand and growth fluctuate. Even the International En- ergy Agency (IEA), with its vast amount of knowledge and data on the subject, admits that energy demand is very hard to predict, in part because there are large uncertainties in economic prospects, energy prices, and government policies [81,91]. According to IEA, the purpose of developing energy scenarios is not to forecast future energy demand but to show how energy demand may evolve under certain circumstances. For some SDG activity levels, however, data only covered a few years. For example, data on collected urban solid waste (Target 11.6) was available only for 2015 and 2016. Using the CAGR from a very short time span to estimate a long-term future might be prob- lematic since a small change in the data might create a large vari- ation in the final result. An interesting comparison could be made between the results of this paper and other methods of estimating future activity levels, such as regression and (excel-based) trendline methods. However, it is beyond the scope of this paper. The above discussion indicates that this research framework can be extended to other countries to evaluate if their current energy policy environment will be sufficient to meet their energy demand under the SDGs regime. Another area of future investigation is energy supply, which should be evaluated for better policy re- sponses related to energy access and security, sustainable energy technology applications, and emission reduction. Future studies should also include a detailed analysis of Table 15 Estimates of CO2 emission in 2030. Scenarios in 2030 BAU SDGs CP Energy use (billion GJ) CO2 emissions (million tonnes) 10.29 722.63 10.76 755.88 12.302 863.39 emissions or environmental impacts. Approximate estimates of carbon emissions calculated using Indonesia's carbon intensity of 2.058 kg of CO2 per kg of oil equivalent primary energy use [92] shows that CO2 emissions may reach 863 million tonnes (or about 2.91 tonnes per capita) if low-carbon transitions are not under- taken, assuming 70% final to primary energy ratio (see Table 15). In comparison, the average CO2 emissions of Indonesia and the lower- middle-income countries were only 1.82 and 1.47 tonnes per capita in 2014, respectively [93]. While a summary of GHG emissions has been provided, a detailed emissions analysis is beyond the scope of this paper. 5. Conclusions and policy implications Mainstreaming the SDGs in national development plans re- quires energy. Countries setting targets to ensure access to food, water, energy, health care, education, and other services to the public should anticipate an increase in their national energy de- mand. Activity levels and energy intensities of the SDG targets that require energy in their implementation can be identified and estimated to predict energy demand at the national level under the SDGs scenario. While the Indonesian final energy demand under the BAU scenario in 2030 will be almost double that in 2015, the demand under the SDGs scenario is expected to be 4.59% higher relative to the demand under the BAU scenario in 2030. It implies that national energy planning in Indonesia should tolerate about 5% more energy demand than the routine estimates if the SDGs are to be accommodated in the national development programs. Fortu- nately, the full implementation of the current energy policy sce- nario will cover the additional demand as a result of the SDGs implementation. The sectoral comparison shows that the transportation sector will consume more energy than the industrial sector under the BAU and SDGs scenarios by 2025. Under the current energy policy sce- nario, however, the industrial sector will still use more energy than the transportation sector by a small margin in 2030 due to the ambitious target of increasing electricity consumption. The current energy policy scenario will significantly increase energy use in the industrial, commercial and household sectors. The energy demand analysis (by fuel) reveals that: Gasoline, electricity, and diesel oil use will increase the most under the BAU scenario. Natural gas, non-energy, and coal consumption will also in- crease significantly by 2030 under the BAU scenario. Under the SDGs scenario, the use of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG will only be slightly higher than that under the BAU scenario. The current energy policy scenario, on the other hand, calls for a dramatic increase in electricity use. A notable increase in natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use should also be expected under this scenario in order to reduce gasoline, diesel, and LPG imports. Finally, this study translates Target 7.3 to a global energy in- tensity benchmark of 3.422 MJ/2011 PPP $ of GDP and combines Targets 7.3 and 8.1 to set a global primary energy use target of less than 73,083 MJ/cap by 2030. Under the current energy policy sce- nario, Indonesia's energy use may reach 3.057 MJ/2011 PPP $ or 57,616 MJ/cap, which will be less than the predicted global average consumption in 2030. The per capita energy consumption in 2030 will also be less than the minimum per capita energy use associated with a very high human development index. The findings of this study have policy implications. First, Indonesia should continue the execution of its national energy plan (RUEN) to ensure that the additional energy demand under the SDGs regime will be met by 2030. The implementation of RUEN in the national development plan will satisfy Indonesia's final energy demand. Next, Indonesia should increase efforts to improve energy effi- ciency and conservation in the transportation sector as the sector will show a remarkable increase in energy demand by 2030. The National Energy Board, through RUEN, has proposed fuel conver- sion programs from petroleum-based fuels to electricity, natural gas, biodiesel, and ethanol. It also suggests the acceleration of efficient public transport and services. A coherent transportation policy is needed to ensure effective inter- ministerial coordination and non-conflicting strategies [94]. Active transportation (walking and bicycling) policies should also be promoted as they will reduce energy use and emissions, improve health and well-being, and may create safer and more sustainable cities and human settlements. In addition, to achieve the ambitious RUEN target of increasing per capita electricity consumption, Indonesia should maintain high economic growth, improve people's living standard, and accelerate the adoption of electric vehicle and cooking stove technologies. These are some factors associated positively with electricity con- sumption [81]. Furthermore, as fossil-based electricity consump- tion is a source of emissions, policy on electricity generation should ensure the adoption of low carbon technology. Declaration of competing interest None. CRediT authorship contribution statement Wayan G. Santika: Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Visualization. M. Anisuzzaman: Conceptualization, Methodology, Writing - review & editing. Yeliz Simsek: Data curation, Writing - original draft. Parisa A. Bahri: Conceptualization, Writing - review & editing, Supervision. G.M. Shafiullah: Writing - review & editing, Supervi- sion. 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Prioritising SDG targets: assessing baselines, gaps and interlinkages. Sustainability Science 2019;14(2):421e38. [4] UNDESA. Voluntary national reviews database. 2019. https:// sustainabledevelopment.un.org/vnrs/. [Accessed 7 August 2019]. [5] Büyüko€zkan G, Karabulut Y, Mukul E. A novel renewable energy selection model for United Nations' sustainable development goals. Energy 2018;165: 290e302. [6] Schwerhoff G, Sy M. Financing renewable energy in AfricaeKey challenge of the sustainable development goals. Renew Sustain Energy Rev 2017;75: 393e401. [7] Caiado RGG, Leal Filho W, Quelhas OLG, de Mattos Nascimento DL, Avila LV. A literature-based review on potentials and constraints in the implementation of the sustainable development goals. J Clean Prod 2018;198:1276e88. [8] dos Santos HTM, Balestieri JAP. Spatial analysis of sustainable development goals: a correlation between socioeconomic variables and electricity use. Renew Sustain Energy Rev 2018;97:367e76. [9] Puig D, Farrell TC, Moner-Girona M. A quantum leap in energy efficiency to put the sustainable development goals in closer reach. Global Policy 2018;9(3):429e31. 2018. [10] Di Foggia G. Energy efficiency measures in buildings for achieving sustainable development goals. Heliyon 2018;4(11). 2018. [11] Alawneh R, Ghazali FEM, Ali H, Asif M. Assessing the contribution of water and energy efficiency in green buildings to achieve United Nations Sustainable Development Goals in Jordan. Build Environ 2018;146:119e32. 2018. [12] Weitz N, Nilsson M, Davis M. A nexus approach to the post-2015 agenda: formulating integrated water, energy, and food SDGs. SAIS Rev 2014;34(2):13. [13] Rasul G. Managing the food, water, and energy nexus for achieving the sus- tainable development goals in south asiavol. 18. Environmental Development; 2016. p. 14e25. [14] Le Blanc D. Towards integration at last? The sustainable development goals as a network of targets. Sustain Dev 2015;23(3):176e87. [15] Santika WG, Anisuzzaman M, Bahri PA, Shafiullah G, Rupf GV, Urmee T. From goals to joules: a quantitative approach of interlinkages between energy and the Sustainable Development Goals. Energy Research & Social Science 2019;50:201e14. [16] McCollum DL, et al. Connecting the sustainable development goals by their energy inter-linkages. Environ Res Lett 2018;13(3):033006. [17] Nerini FF, et al. Mapping synergies and trade-offs between energy and the sustainable development goals. Nature Energy 2018;3(1):10e5. [18] W. G. Santika, T. Urmee, M. Anissuzaman, G. Shafiullah, and P. A. Bahri, "Sustainable energy for all: Impacts of Sustainable Development Goals implementation on household sector energy demand in Indonesia," presented at the The 2018 International Conference on Smart-Green Technology in Electrical and Information Systems, Bali, 25 October 2018, 2018. [19] Bappenas. Voluntary National Review: eradicating poverty and promoting prosperity in a changing world. Jakarta: National Development Planning Agency (BAPPENAS); 2017. https://sustainabledevelopment.un.org/content/ documents/15705Indonesia.pdf. [20] MEMR. Rencana Umum Energi Nasional (National Energy General Plan). Jakarta: Ministry of Energy and Mineral Resources; 2017. [21] BPPT. Indonesia energy outlook. Badan Pengkajian Dan Penerapan Teknologi; 2018. https://bppt.go.id/outlook-energi/bppt-outlook-energi-indonesia-2018. [22] Heaps CG. Long-range Energy Alternatives Planning (LEAP) system. 2016. https://www.energycommunity.org/default.asp?action¼home. [23] Carroll A, Heiser G. An analysis of power consumption in a smartphone. USENIX annual technical conference, vol. 14; 2010. 21-21: Boston, MA. [24] Connolly D, Lund H, Mathiesen BV, Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. Appl Energy 2010;87(4):1059e82. [25] Urban F, Benders R, Moll H. Modelling energy systems for developing coun- tries. Energy Pol 2007;35(6):3473e82. [26] Ouedraogo NS. Modeling sustainable long-term electricity supply-demand in Africa. Appl Energy 2017;190:1047e67. [27] Mondal MAH, Bryan E, Ringler C, Mekonnen D, Rosegrant M. Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions. Energy 2018;149:161e72. [28] Mirjat NH, Uqaili MA, Harijan K, Walasai GD, Mondal MAH, Sahin H. Long- term electricity demand forecast and supply side scenarios for Pakistan (2015e2050): a LEAP model application for policy analysis. Energy 2018;165: 512e26. [29] Prasodjo E, et al. Indonesia energy outlook 2016. Jakarta: National Energy Council of Indonesia; 2016. http://esdm.go.id/assets/admin/file/pub/IEO__2016_English_ver.pdf. [30] Handayani K, Krozer Y, Filatova T. Trade-offs between electrification and climate change mitigation: an analysis of the Java-Bali power system in Indonesia. Appl Energy 2017;208:1020e37. [31] Wijaya ME, Limmeechokchai B. The hidden costs of fossil power generation in Indonesia: a reduction approach through low carbon society. Songklanakarin J Sci Technol 2010;32(1):81e9. [32] Kumar S. Assessment of renewables for energy security and carbon mitigation in Southeast Asia: the case of Indonesia and Thailand. Appl Energy 2016;163: 63e70. [33] Memr. Handbook of energy & economic statistics of Indonesia 2018. Jakarta: Ministry of Energy and Mineral Resources; 2018. [34] Memr. Handbook of energy & economic statistics of Indonesia 2017. Jakarta: Ministry of Energy and Mineral Resources; 2017. [35] Memr. Handbook of energy & economic statistics of Indonesia 2012. Jakarta: Ministry of Energy and Mineral Resources; 2012. [36] Bappenas, Bps, and Unfpa. Indonesia population projection 2010-2035. Jakarta: BPS; 2013. p. 470. [37] World Bank. Prevalence of undernourishment (% of population). 2018. https:// data.worldbank.org/indicator/SN.ITK.DEFC.ZS?locations¼ID. [Accessed 4 January 2019]. [38] Said NI. Pengolahan Air Limbah Domestik di DKI Jakarta. Jakarta: BPPT; 2008. [39] Miller LA, Ramaswami A, Ranjan R. Contribution of water and wastewater infrastructures to urban energy metabolism and greenhouse gas emissions in cities in India. J Environ Eng 2012;139(5):738e45. [40] Smith K, Liu S, Liu Y, Guo S. Can China reduce energy for water? A review of energy for urban water supply and wastewater treatment and suggestions for change. Renew Sustain Energy Rev 2018;91:41e58. [41] Bps, "2012-2016. Indonesian energy balance. Jakarta: BPS-Statistics Indonesia; 2017. [42] Pellegrini P, Fernandez RJ. Crop intensification, land use, and on-farm energy- use efficiency during the worldwide spread of the green revolution. Proc Natl Acad Sci Unit States Am 2018;115(10):2335e40. [43] Bps, "Berita Resmi Statistik. Hasil sensus pertanian 2013. Jakarta: BPS-Statis- tics Indonesia; 2013. Available at: https://www.bps.go.id/pressrelease/2013/ 12/02/973/rumah-tangga-petani-gurem-2013-turun-25-07-persen-diban- dingkan-2003.html. [44] Bappenas. 3.8.1 (a)_Unmet need pelayanan kesehatan_Nasional.csv. 2017. http://hub.satudata.bappenas.go.id/dataset/unmet-need-pelayanan-kese/ resource/4748ed7a-9118-411f-8357-f3c6aae98149. [Accessed 3 February 2019]. [45] Kemendikbud. APK/APM PAUD, SD, SMP, dan SM Tahun 2016/2017. Jakarta: Ministry of Education and Culture; 2017. http://publikasi.data.kemdikbud.go. id/uploadDir/isi_EC3D363B-1665-45AB-9058-C30537F5C50B_.pdf. [46] Kemendikbud. APK/APM PAUD, SD, SMP, dan SM 2014/2015. Jakarta: Ministry of Education and Culture; 2015. http://publikasi.data.kemdikbud.go.id/ uploadDir/isi_AD36B60F-16E8-4515-ABBB-81D808FFDAAF_.pdf. [47] National Education Ministrial Regulation, vol. 24; 2007. [48] Energy and Mineral Resources Ministrial Regulation, vol. 13; 2012. [49] BPS. Education indicators, 1994-2017. BPS Statistics Indonesia; 2017. https:// www.bps.go.id/statictable/2010/03/19/1525/indikator-pendidikan-1994- 2017.html. [Accessed 30 March 2019]. [50] BPS. Population 15 Years of age and over by age group and type of activity during the previous week, 2008 - 2018. BPS-Statistics Indonesia; 2019. https://www.bps.go.id/statictable/2016/04/04/1904/penduduk-berumur-15-tahun-ke-atas-menurut-golongan-umur-dan-jenis-kegiatan-selama-seminggu-yang-lalu–2008—2018.html. [Accessed 30 March 2019]. [51] BPS. Proportion of individuals who use mobile phones by sex, 2015 -2016. BPS-Statistics Indonesia; 2019. https://www.bps.go.id/dynamictable/2018/05/ 21 00:00:00/1350/proporsi-individu-yang-menggunakan-telepon- genggam-menurut-jenis-kelamin-2015—2016.html. [Accessed 30 March 2019]. [52] Smith K, et al. Impact of urban water supply on energy use in China: a pro- vincial and national comparison. Mitigation and adaptation strategies for global change, vol. 21; 2016. p. 1213e33. 8. [53] BPS. Welfare statistics 2015. Jakarta: BPS-Statistics Indonesia; 2015. [54] BPS. Welfare statistics 2017. Jakarta: BPS-Statistics Indonesia; 2017. [55] MEMR. Electricity statistics 2015. Jakarta: Directorate General of Electricity of the Ministry of Energy and Mineral Resources; 2016. [56] MEMR. Statistics of electricity and energy 2008. Jakarta: Ministry of Energy and Mineral Resources; 2008. [57] BPS. Percentage of household population by province and type of cooking fuel 2007-2016. BPS-Statistics Indonesia; 2017. https://www.bps.go.id/statictable/ 2014/09/10/1364/persentase-rumah-tangga-menurut-provinsi-dan-bahan- bakar-utama-untuk-memasak-tahun-2001-2007-2016.html#. [Accessed 18 June 2018]. [58] Gujba H, Mulugetta Y, Azapagic A. The household cooking sector in Nigeria: environmental and economic sustainability assessment. Resources 2015;4(2): 412e33. [59] Bappenas. National medium-term development plan 2015-2019: book 1. 2014. http://www.social-protection.org/gimi/gess/RessourcePDF.action?ressource.ressourceId¼50077. [60] Ministry of Public Works and Housing. Buku informasi statistik 2017 (2017 statistic information book). Jakarta: The Ministry of Public Works and Hous- ing; 2017. [61] European Commission Energy. Energy conservation in road pavement design, maintenance and utilisation. European Commission Energy; 2010. https://ec. europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/ documents/ecrpd_publishable_report_en.pdf. [62] BPS. Statistik telekomunikasi Indonesia 2011 (2011 Indonesia's telecommu- nication statistics). Jakarta: BPS-Statistics Indonesia; 2012. [63] BPS. Telecommunication statistics in Indonesia 2015. Jakarta: BPS-Statistics Indonesia; 2016. [64] BPS. Percentage of urban slum households by province, 2015-2016. BPS-Sta- tistics Indonesia; 2018. https://www.bps.go.id/dynamictable/2018/08/14/ 1561/persentase-rumah-tangga-kumuh-perkotaan-menurut-provinsi-2015- 2016.html#. [Accessed 16 November 2018]. [65] Atmaca A, Atmaca N. Comparative life cycle energy and cost analysis of post- disaster temporary housings. Appl Energy 2016;171:429e43. [66] Newman P, Kenworthy J. Evaluating the transport sector's contribution to greenhouse gas emissions and energy consumption. In : Salter R, Dhar S, Newman P, editors. Technologies for climate change mitigation-transport sector; 2011. p. 7e23. Roskilde: UNEP Riso Centre on Energy, Climate and Sustainable. [67] BPS. Percentage of households with main freight used to work and school, 2014. BPS-Statistics Indonesia; 2018. https://www.bps.go.id/dynamictable/ 2018/05/24 00:00:00/1367/persentase-rumah-tangga-dengan-angkutan- utama-yang-biasa-digunakan-menuju-ke-tempat-bekerja-dan-sekolah-2014. html. [Accessed 21 November 2018]. [68] BPS. Environment statistics of Indonesia 2017. Jakarta: BPS-Statistics Indonesia; 2017. [69] Beigl P, Salhofer S. Comparison of ecological effects and costs of communal waste management systems. Resour Conserv Recycl 2004;41(2):83e102. [70] FAO. In: Energy-smart food for people and climate. Rome: Food and Agri- culture Organization; 2011. http://www.fao.org/docrep/014/i2454e/i2454e00. pdf. [71] Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R, Meybeck A. In: Global food losses and food waste: extent, causes and prevention. Rome: Food and Agriculture Organization; 2011. [72] Cleary J. Life cycle assessments of municipal solid waste management sys- tems: a comparative analysis of selected peer-reviewed literature. Environ Int 2009;35(8):1256e66. [73] Presidential regulation 97/2017. 2017. [74] Damanhuri E. State of the 3Rs in asia and the pacific: country chapter-the republic of Indonesia. Nagoya: United Nations Centre for Regional Develop- ment and Institute for Global Environmental Strategies; 2017. [75] BPS. Number of deaths, disappeared, and hurt victims affected by 100,000 people, 2011 - 2016. BPS-Statistics Indonesia; 2018. https://www.bps.go.id/ dynamictable/2018/05/24 00:00:00/1368/jumlahkorban-meninggal- hilang-dan-terluka-terkena-dampak-bencana-per-100-000-orang-2011— 2016.html. [Accessed 21 November 2018]. [76] World Bank. Fixed broadband subscriptions (per 100 people). 2018. https:// data.worldbank.org/indicator/IT.NET.BBND.P2?locations¼ID&view¼chart. [Accessed 22 November 2018]. [77] Hinton K, Baliga J, Feng M, Ayre R, Tucker RS. Power consumption and energy efficiency in the internet. IEEE Network 2011;25(2). [78] BPS. Proportion of individuals who use the internet by province, 2015 - 2016. BPS-Statistics Indonesia; 2018. https://www.bps.go.id/dynamictable/2018/05/ 21 00:00:00/1351/proporsi-individu-yang-menggunakan-internet- menurut-provinsi-2015—2016.html. [Accessed 22 November 2018]. [79] Vilhelmson B, Thulin E, Ellder E. Where does time spent on the Internet come from? Tracing the influence of information and communications technology use on daily activities. Inf Commun Soc 2017;20(2):250e63. [80] Menezes A, Cripps A, Buswell RA, Wright J, Bouchlaghem D. Estimating the energy consumption and power demand of small power equipment in office buildings. Energy Build 2014;75:199e209. [81] Ugursal VI. Energy consumption, associated questions and some answers. Appl Energy 2014;130:783e92. [82] Kankal M, Akpınar A, Ko€mürcü MI_, O€zşahin TŞ. Modeling and forecasting of Turkey’s energy consumption using socio-economic and demographic vari- ables. Appl Energy 2011;88(5):1927e39. [83] ADB. Nepal energy sector assessment, strategy, and road map. Manila: Asian Development Bank; 2017. https://www.adb.org/sites/default/files/ publication/356466/nepal-energy-assessment-road-map.pdf. [84] IEA and World Bank. Sustainable energy for all 2015: progress toward sus- tainable energy. Washington DC: World Bank; 2015. [85] World Bank. World development indicators: sustainable development goals. 2019. http://datatopics.worldbank.org/sdgs/. [Accessed 20 March 2019]. [86] World Bank. GDP per capita, PPP (constant 2011 international $). 2019. https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD?locations¼ID-1W. [Accessed 29 May 2019]. [87] World Bank. Energy use (kg of oil equivalent per capita). 2019. https://data. worldbank.org/indicator/EG.USE.PCAP.KG.OE? locations¼XD-XM-XN-XP-XT. [Accessed 29 May 2019]. [88] Steinberger JK, Roberts JT. From constraint to sufficiency: the decoupling of energy and carbon from human needs, 1975e2005. Ecol Econ 2010;70(2): 425e33. [89] World Bank. Access to clean fuels and technologies for cooking (% of popu- lation). 2019. https://data.worldbank.org/indicator/EG.CFT.ACCS.ZS? locations¼ID. [Accessed 17 June 2019]. [90] Terrapon-Pfaff J, Dienst C, Ko€nig J, Ortiz W. How effective are small-scale energy interventions in developing countries? Results from a post- evaluation on project-level. Appl Energy 2014;135:809e14. [91] IEA. World energy outlook 2012. Paris: International Energy Agency; 2012. [92] World Bank. CO2 intensity (kg per kg of oil equivalent energy use) - Indonesia. 2019. https://data.worldbank.org/indicator/EN.ATM.CO2E.EG.ZS? locations¼ID. [Accessed 20 October 2019]. [93] World Bank. CO2 emissions (metric tons per capita) - Indonesia, Lower middle income. 2019. https://data.worldbank.org/indicator/EN.ATM.CO2E.PC? locations¼ID-XN. [Accessed 21 October 2019]. [94] NAMA Facility. Sustainable urban transport programme in Indonesia (SUTRI NAMA). Berlin: NAMA Facility; 2017. https://www.nama-facility.org/ fileadmin/user_upload/publications/factsheets/2017-11_factsheet_nama-facility_indonesia_sutrinama.pdf.