Document Viewer

Turnitin Originality Report

Processed on: 11-May-2023 10:20 AM EDT
ID: 2090419062
Word Count: 14806
Submitted: 1

ERSS 2019 By Wayan S

Similarity Index	Similarity by Source	
14%	Internet Sources:	13%
	Publications:	14%
	Student Papers:	9%

include quoted | exclude bibliography | excluding matches < 1% | mode: quickview (classic) report | print | refresh | download

5% match ()
Santika, I Wayan Gede. "A framework for translating Sustainable Development Goals into national energy planning in developing countries: The case of Indonesia", 2021

4% match (Wayan G. Santika, M. Anisuzzaman, Yeliz Simsek, Parisa A. Bahri, G.M. Shafiullah, Tania Urmee. "Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia", Energy, 2020)
Wayan G. Santika, M. Anisuzzaman, Yeliz Simsek, Parisa A. Bahri, G.M. Shafiullah, Tania Urmee. "Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia", Energy, 2020

2% match (student papers from 11-Nov-2021)
Submitted to De Montfort University on 2021-11-11

2% match (Internet from 07-Oct-2022)
https://www.researchgate.net/publication/330350801_From_goals_to_joules_A_quantitative_approach_of_interlinkages_between_energy_

1% match (student papers from 11-Nov-2021)
Submitted to De Montfort University on 2021-11-11

1% match (student papers from 11-Nov-2021)
Submitted to De Montfort University on 2021-11-11

1% match (Internet from 11-Feb-2023)
https://www.researchgate.net/publication/228467273_Comparison_of_ecological_effects_and_costs_of_communal_waste_management_s

Energy Research & Social Science 50 (2019) 201–214 Contents lists available at ScienceDirect Energy Research & Social Science journal homepage: www.elsevier.com/locate/erss From goals to joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals T Wayan G. Santikaa,b, M. Anisuzzamana, Parisa A. Bahria, G.M. Shafiullaha, Gloria V. Rupfa, Tania Urmeea,⁎ a School of Engineering and Information Technology, Murdoch University, 90 South Street, Murdoch, Western Australia, 6150, Australia b Department of Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia ARTICLE INFO ABSTRACT Keywords: Sustainable Development Goals SDGs Energy planning SDGs interlinkages Energy intensity Energy demand Energy is a key enabler in achieving the Sustainable Development Goals (SDGs) as energy plays the pivotal role in ending poverty and hunger, providing healthcare, education, and water, as well as sustaining economic growth and protecting the environment. Consequently, since the SDGs are executable only at local and national levels, mainstreaming the SDGs into local/national development planning will put pressure on the country's energy sector. Considering the broad scope of the SDGs, countries will prioritize different SDG targets based on their urgencies, resources, and capabilities. However, energy linkages with the SDGs and their targets are complex, with direct and indirect connections, synergies, and trade-offs. More importantly, there is a lack of capacity among policymakers to be able to develop an SDGs-responsive energy plan, as there is no guidance on how the impact of linkages can be translated into local/national energy planning. This study aims to examine the complexity of the interconnections between energy and the SDGs, as well as give examples of how these linkages can be quantified. Twenty-five SDG targets with direct links to energy are identified in this study, and a map of the multidimensional interaction between them are presented. The study also provides examples of quantifi- cation of the targets/indicators into their energy requirements. The results of the study will help energy planners and policymakers forecast energy demand more accurately for energy planning and policies under the SDGs regime. 1. Introduction As a key enabler for the Sustainable Development Goals (SDGs), energy increases productivity, transforms economies and societies, and improves human life in terms of economic growth, food production, well-being and healthy lifestyles, education, gender equality and em- powerment, water supply and sanitation, as well as employment [1]. The SDGs are global goals yet executable only in local and national contexts, and the implementation of the SDGs into local and national development planning will affect the energy sector. More energy will be required if a country strives to end poverty; eradicate hunger; improve health and well-being, education, and gender equality; provide clean water and energy; and achieve the other SDGs. Studies have shown a strong correlation between per capita energy consumption and the human development index (HDI) [2–4]. They have found high and moderate increases in human welfare relative to energy use in the least developed countries and the transitioning na- tions, respectively. In contrast, saturation is found in developed nations, as consuming vast amounts of energy has no significant impact on human development [2,5]. However, it does not imply that the SDGs are relevant for developing countries only [6]. While the developing countries focus on access to basic needs, e.g., ending extreme poverty, the rich nations will address issues related to responsible consumption and production, climate change, and biodiversity [7,8]. The challenge lies in finding ways to accommodate this energy demand with modern and sustainable energy services and the global natural resources considering their impact on the environment to en- sure that the SDGs are well addressed. It poses difficulty in developing an energy plan that can adequately respond to the context of the SDGs in the understanding of how the achievement of different SDG targets will impact the energy supply and demand scenarios. It is because, on the one hand, the achievement of most SDG targets will require energy as an input, which will give rise to the energy demand. On the other hand, changes in one SDG target may influence the energy demand of other targets, as well as on how the energy resources are being utilized to supply the required energy. The SDGs also imply that energy decision ⁎ Corresponding author. E-mail address: T.Urmee@murdoch.edu.au (T. Urmee). https://doi.org/10.1016/j.erss.2018.11.016 Received 30 July 2018; Received in revised form 25 November 2018; Accepted 28 November 2018 2214-6296/ © 2018 Elsevier Ltd. All rights reserved. makers should consider the impacts of their choices on the environment [9]. To the authors' knowledge, no study discusses the quantification of SDG targets and indicators into energy demand. The global research community is still building up their knowledge on how the SDGs will work at the national level and how the additional energy requirement can be quantified to ensure that all SDGs are adequately achieved. It includes discussions on the interconnectedness and cross-impacts of the SDGs, and how the countries would need to plan to achieve them. Le Blanc [10], for example, provides interlinkages and mapping of the

SDGs as a network of targets based solely on the targets' wording. Since it only assesses the relationships purely on the wording content of the targets, the method cannot be used to acknowledge other distinct in- terconnections adequately. As an example, based on its targets' wording, the energy goal (SDG 7) is linked only to 3 other goals, which are inequality (SDG 10), sustainable consumption and production (SDG 12), and poverty (SDG 1). 1 The links between energy and health (SDG 3), education (SDG 4), climate change mitigation (SDG 13), food (SDG 2), and water (SDG 6), among others, were not distinct. Another study proposed a nexus approach to explain the complexity of the SDG net- work of food, energy, and water [11]. Exploring the nature of inter- connections among targets, it provided possible nexus interactions be- tween some SDG targets related to energy, water, food, health, and education. Compared to the previous approach, this method is more comprehensive in explaining the interactions. The nexus approach, however, increases the complexity of the analysis and makes it harder to quantify the corresponding energy requirements. Additionally, the International Council for Science (ICSU) [12] and Nerini, et al. [13] have mapped the linkages between the energy goal and other SDGs and the studies are claimed to be based on scientific evidence. The ICSU's SDGs and energy linkages are based on the In- ternational Institute for Applied Systems Analysis (IIASA) working paper which concludes that SDG 7 (energy) is interconnected with all other SDGs [14,15]. The mapping of Nerini et al. [13] identifies 143 targets and 65 targets as having synergies and trade-offs with SDG 7, respectively. However, those studies do not address the impacts of pursuing the targets on the energy demand dynamics, e.g., what the additional energy requirement for ending hunger is by 2030. Moreover, some of the targets proposed as related to energy are either social, in- stitutional, policy, or regulatory targets, which have no direct links to energy demand. Some other targets have been covered by others or are difficult to quantify. Various energy demand models are available to assist national planners in quantifying energy demand and supply, such as the Long- range Energy Alternatives Planning (LEAP), OSeMOSYS (Open Source Energy Modeling System), NEMS (The National Energy Modeling System) and MARKAL, that would presumably be able to model energy demand associated with different targets. However, these models are unable to capture additional energy requirements arising from the in- terlinkages between energy and other SDGs due to the lack of a me- chanism for estimating this additional energy demand. This lack of a coherent approach or methodology that can quantify the energy re- quired to achieve each SDG target poses an enormous difficulty for policymakers, particularly to enable them to develop an energy plan that is sufficient and responsive to realizing the SDG goals by 2030. This gap is thus a strong barrier to the achievement of the SDGs globally. First, the SDG targets that have strong and direct impacts on the energy demand and supply will need to be identified. While some targets may have flow-on effects on energy demand, for simplicity, this paper will consider only the first-order linkages of SDG targets with energy. It is 1 The coding of targets and indicators in the remainder of the paper will follow the coding of the UN official revised list of global SDG indicators. Target 1.4 means the fourth target of SDG 1 (the first goal). Indicator 1.4.2 indicates the second indicator of Target 1.4. the authors' opinion that data and information availability to estimate energy demands for the second and subsequent orders of linkages is inadequate, and thus it will not be attempted in this paper. As men- tioned above, various studies have endeavored to map the interlinkages between energy and SDG targets. A review of those studies will lead to an interlinkages map that is robust and widely acceptable. The energy requirement for each of those interlinkages will then need to be quantified in a way that determines the additional energy requirement for achieving SDG targets compared to the business-as-usual (BAU) scenario, i.e., if the SDGs were not to be mainstreamed. 2. Background The United Nations defined the SDGs as "a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity" [16]. They include five P's essential to humanity, i.e., the people, the planet, prosperity, peace, and partnership. The SDGs are a global commitment pledged by state members of the United Nations incorporating 17 goals, 169 targets, and 232 indicators. However, even though the SDGs and their targets are meant to be achieved globally, they can only be executed at national and local levels. For example, Target 2.1 aims to end hunger globally by 2030. The target can be measured using the prevalence of undernourishment (Indicator 2.1.1). According to the Food and Agriculture Organization (FAO) data, about 800 million people in the world were estimated to live in hunger be- tween 2014 and 2016 [17]. The two most populous countries in the world, India and China, have 15.2% and 9.3% undernourishment re- spectively, which means that almost 330 million people in these two countries would not have enough food to eat regularly. Under- nourishment in India and China corresponds to 109 kcal and 74 kcal food deficit per person per day respectively [18]. It equates to ap- proximately 21,255 million kcal and 9990 million kcal worth of food per day to end hunger in India and China, respectively, by 2030. In efforts to end hunger and to produce enough food for everyone in these two countries (Target 2.1), additional energy will be required at dif- ferent stages of food production and value chain, e.g., for cultivation, fertilizer, irrigation, harvesting, processing, storing and transporting. Similarly, Target 6.1 requires access to safe drinking water for all. Its indicator is the proportion of the population using safely managed drinking water services (Indicator 6.1.1). The World Health Organization shows that about 71% of the global population consumed safe drinking water in 2015 [19]. However, almost half of the world rural population lacked access during the same period. For example, less than 7% of Ugandans were served with consumable water in 2015. Based on a water requirement of at least 50 liters/person/day [20], 1.88 million m3 of additional water will be needed daily to provide safe drinking water for everyone in Uganda by 2030. In Cambodia and Pakistan, less than 50% of the population have access to safe drinking water in 2015 [19]. Both countries should also consider mainstreaming Target 6.1 into their national plans. We estimate that in the absence of the SDGs only about 85% of the global population will have safe, consumable water by 2030. Water production requires energy, e.g., for abstraction, conveyance, treatment, and pumping. A significant amount of additional energy will be required at the national level to ensure universal access to safe drinking water. 2.1. Overview of SDG 7 Energy, a vital element in achieving the SDGs, is included as SDG 7: "Ensure access to affordable, reliable, sustainable and modern energy for all." Modern energy comprises electricity, clean fuels and technology for cooking, and mechanical power (i.e., converted energy to motion for pumping and pushing) [21]. There are three primary targets under SDG 7, which represent the three pillars of sustainable energy, i.e., ensuring access to clean and modern energy, increasing the share of renewable energy, and doubling energy efficiency. The proportion of the Table 1 Sustainable Energy for All (SEforALL) global objectives, baselines, and IEA estimates. Source: IEA and the World Bank [22] Access to electricity Access to clean cooking fuels and Renewable energy share in Energy efficiency (measured as the annual growth rate of technologies TFEC primary energy intensity) 2030-Objectives 2014-Baseline 2030-IEA estimates 100% 85.3% 91% 100% 36% −2.6% 57.4% 18.3% −2.1% 72% 21% −2.1% population with access to electricity and the ratio of the population with clean fuels and technology are the indicators measuring clean and modern energy access. The indicators for the second and third targets are renewable energy share in the total final energy consumption and energy intensity measured in terms of primary energy supply per unit of Gross Domestic Product (GDP), respectively. The SDG 7 targets have been primarily based on the Sustainable Energy for All (SEforALL) objectives for 2030, which was announced in 2012 [22]. SEforALL is a United Nations global initiative to promote actions based on commitments to providing universal access to sus- tainable energy in recognition of its importance to sustainable devel- opment. Table 1 summarises the SEforALL global objectives for 2030, its baseline conditions, and the International Energy Agency (IEA) es- timates for 2030. It shows that access to electricity and clean energy for cooking are set to be universal (100%) by 2030, while the baseline situations are 85.3% and 57.4%, respectively. However, the IEA esti- mates that access to electricity and clean energy for cooking will reach only about 91% and 72% of the population by 2030, respectively, even if the IEA's New Policies Scenario is fully applied [22]. The New Po- licies Scenario considers energy policies that are under implementation as well as targets, aims, and intentions that have been announced but are yet to be implemented, such as the Nationally Determined Con- tributions (NDC) [23]. Similarly, the IEA predicts that the global renewable energy share of total final energy consumption (TFEC) will only be 21% by 2030, far below the target. The annual growth rate of the primary energy in- tensity will be around -2.1%, slightly below the 2030 target. When the SEforAll was initiated, the growth rate was -1.3% (2010-baseline) [24]. To ensure universal access to affordable, reliable and modern en- ergy services, we should anticipate an increase in energy demand. For example, providing electricity globally for 1.2 billion people who lack access [23] means that around 109.5 TWh electricity should be added by 2030. It is based on a household electricity consumption of 365 kWh per year (Tier 3 of the World Bank's Multi-Tier Framework for mea- suring electricity access) [25]. Similarly, 59.4 million metric tons of LPG equivalence will be required by 2030 to provide clean energy for cooking for the 2.7 billion people who currently cook using traditional biomass (based on the IEA [26] estimate of 22 kg annual consumption of LPG per capita in developing countries). 2.2. Energy reduction potential It is clear that some targets will potentially reduce energy consumption. For instance, Target 7.3 calls for doubling the rate of energy efficiency, and its potential reduction will not be small. Cullen et al. [27] found that 73% energy reduction is possible by changing the de- sign of passive systems using the most efficient technology that prac- tically achievable. The saturation phenomena previously discussed indicate that en- ergy reduction is possible while maintaining high human development [2,5]. As high human development can be achieved with as low as 63 GJ of energy per capita, scholars have suggested that high income countries should reduce their energy consumption [4,28], even though the decoupling of energy consumption from human development is highly overestimated [29]. However, the main driver of energy consumption is the economic growth and vice versa, and reducing consumption will have a negative impact on growth unless the reduction is achieved through energy ef- ficiency [30]. Energy efficiency implies the delivery of the same level of services using less energy. The study also suggests that increasing en- ergy prices to curtail consumption will negatively impact the economy [30]. Studies about the relationship between energy and economic growth also show conflicting results [31–34]. A literature survey re- viewing 48 studies about the link indicates that about half of the studies found causal relationships from energy to growth, suggesting that en- ergy reduction will give an adverse effect to the economic growth [34]. Half others demonstrate that consumption can be reduced without af- fecting growth. We will discuss this reduction potential further when we review Targets 7.3 and 8.1 in the quantification and discussion chapters. 3. Methods The study has been conducted in five key steps. First, in the Google Scholar search engine, we used keywords related to the goals. For ex- ample, in relation to SDG 2 about ending hunger, we used keywords such as 'energy and food,' 'energy consumption and agriculture,' 'electricity use and food' and 'energy access and hunger.' We also used the Google search engine to include evidence from the 'grey' literature. The collection of evidence was sorted to come up with the most relevant sample of literature. The list is not intended to be exhaustive since other studies [12–14] have provided more comprehensive records. We con- sider this step important to gain more knowledge about the linkages, which is essential for the second step. Second, a simple qualitative content analysis [35–37] was con- ducted to identify SDG targets with strong links to energy demand. The analysis was based on the explicit content of the written texts of each SDG targets and indicators. Three conditions are set to identify if a target is linked to energy demand. They are (1) implementation of the target requires energy or reduce energy consumption, (2) the target is quantifiable in term of energy, and (3) the target has not been covered by other targets. A target should comply with all conditions to be identified as linked to energy demand. Authors meetings and expert consultations were held to interpret the content of each target and to review results until consensus is reached. Authors of this paper dis- cussed to arrive at a correct interpretation of the content of all SDG targets and indicators word-by-word to come up with the list of targets with strong links to energy demand. Third, we illustrate the complexity of linkages between energy and SDG targets based on the list of identified linkages between energy and targets, and group the targets based on sectors. The mapping also re- cognizes the second layer of interaction between energy and targets/ indicators (the indirect link between energy and SDG targets). Next, independent energy experts with comprehensive experience in energy, sustainable development planning and policy, and climate change were consulted to comment on the revised list and the linkage map. The consultation was conducted through email correspondence and fina- lized with a teleconference. Finally, it presents an in-depth quantitative analysis based on empirical evidence to quantify additional energy demand for each of the targets included in the synthesized interlinkages map. As mentioned earlier, this analysis addresses only first-order interactions between energy and SDG targets. The approach mainly uses algebraic manip- ulations to translate the SDG targets to their energy demand equiva- lence (in MJ/capita or MJ per unit of SDG indicators). Targets were translated into mathematical equations, which then were solved by using data for relevant targets. As this analysis aimed at developing a general framework to quantify additional energy requirement per unit of SDG activity using global data, a small margin of error could be possible if the model is directly applied at a national level. This margin of error could be eliminated/improved by using country-specific data, where available, into the equations that have been presented in this paper. This quantification of energy demand for each of the energy-linked SDG targets is the core and original work presented in this paper and is believed to introduce a new paradigm of SDG-responsive energy plan- ning at national levels. The total additional energy demand at a na- tional level can be determined by summing up the extra energy re- quired for all targets, and a set of recommendations can be presented for policymakers. 4. Interlinkages between energy and SDGs Our collection of evidence sorts 88 samples of scientific and grey literature that support linkages between energy and the SDGs (see Appendix A for the list of evidence). There are samples of literature supporting every linkage between energy and the SDGs [13–15]. However, a closer look at the target level shows that targets of SDG 10, 14, 15, and 16 do not have strong or direct links with energy demand and can be omitted in this study, but they may have some implications on other aspects of energy. The qualitative content analysis identifies only 25 targets with sig- nificant links to energy demand (Appendix B). The authors note that there are more targets with direct links to energy. However, these have been excluded for the reasons previously mentioned: they have been covered by other targets, the link with energy demand is difficult to quantify, or there is only a weak relationship. For instance, Targets 1.1, 1.2, and 1.3 are related to poverty eradication in all its dimensions. These targets are excluded considering that most other targets will contribute to them. Similarly, Target 10.1, which refers to the accel- eration of the income growth of the bottom 40% of the population, is omitted because it has been addressed by Target 8.1. The analysis ex- cludes the targets of SDG 10, 14, 15, and 16 for similar reasons. The results were compared with those of Nerini et al. [13] and McCollum et al. [14] and found that Target 5.b, which is about in- formation and communication technology (ICT) to empower women, is not in the list of Nerini et al. We argue that achieving Target 5.b will require energy. We also found that targets related to the means of im- plementation (Targets 5.b, 9.c, 17.6, and 17.8) that we consider related to energy demand are not in the list of McCollum et al. [14]. They omit the means of implementation targets entirely from the analysis while we assert that those four targets (about ICT and access to internet) are linked to and will increase energy demand. Fig. 1 illustrates the complexity of the interconnections between energy demand and SDG targets and indicators. The circles represent either targets or indicators, and those of the same color belong to the same goal. The direction of the arrows indicates the orientation of the effects. For instance, ensuring access to housing (Target 11.1) will in- fluence energy demand and contribute to access to basic services (Target 1.4). Blue arrows mean that the targes will increase energy demand while the green and grey ones reduce energy demand and neutral, respectively. For example, increasing the share of renewable energy (Target 7.2) will change the composition of energy sources (fuels), but it will not increase or decrease energy demand. The energy- related targets and indicators are grouped into 11 sectors: transport; information and communications technology (ICT); education; energy demand and supply; built environment; health; water sanitation and hygiene (WASH); food and agriculture; waste management; climate change adaptation; and economy and industry. As an illustration, providing access to basic services for everyone (Target 1.4) requires energy. Basic services include access to transpor- tation, telecommunication, education, energy, healthcare, safe drinking water, sanitation, waste management, social welfare, public safety, and open space management [38]. Therefore, achieving Targets 3.8, 4.1, 4.2, 4.3, 6.1, 7.1, 9.1, 9.c, 11.1, 11.2, and 11.6 will contribute to the achievement of Target 1.4. The interaction of Targets 2.1 and 2.3 (food production and access) with Target 7.2 (increasing renewable energy share), has to be carefully considered. In many cases, energy and food compete for land and water resources. Growing plants for biofuels, for example, requires land and water that otherwise can be used for agriculture [39,40]. Another study shows that replacing a significant amount of petroleum with ethanol production from corn and biodiesel production from soybean in the US cannot be done without affecting food supplies [41]. Another subtle linkage, which can be easily overlooked, is in rela- tion to Indicator 9.1.1 (access to rural road infrastructure). The con- struction of road networks requires energy. Once built, an improved road network will attract more vehicles [42], which will further in- crease energy demand in the transport sector. Similarly, success in doubling the energy efficiency may stimulate further consumption. Experts are cautious about the effectiveness of energy efficiency in re- ducing consumption due to the phenomenon called rebound effect [43–45]. The rebound effect indicates that any saving as a result of efficiency measures may encourage more consumption [46]. For ex- ample, efficient cars reduce energy consumption per travel, which in turn, may motivate more trips and increase the overall energy con- sumption. 5. Quantification of energy demand at target levels Once the interlinkages have been mapped, the targets or their in- dicators were translated into energy demand. In general, multi-di- mensional linkages add complexity to the energy demand equation. To estimate the energy requirements for achieving these targets we calculated the first-order connection only. The details are explained below. 5.1. SDG 1 – no poverty Target 1.4. The target requires universal access to basic services for all which is to be measured by Indicator 1.4.1 - Proportion of population living in households with access to basic services. As explained in Section 3, basic services include access to transportation, telecommunication, education, energy, healthcare, safe drinking water, sanitation, waste management, social welfare, public safety, and the open space man- agement. This target is covered by other targets, including Targets 3.8, 4.1, 4.2, 4.3, 6.1, 7.1, 9.1, 9.c, 11.1, 11.2, and 11.6, and so has not been included in energy quantification. 5.2. SDG 2 – zero hunger Target 2.1. The target is to end hunger and provide sufficient food for everyone, and measurable using Indicator 2.1.1 - Prevalence of un- dernourishment. Undernourishment is represented by the country's depth of food deficit (DF). According to the data provided by the World Bank [18], DF is estimated to be 90.25 kcal/person/day, globally. The energy intensity (EI2.1) can be determined using the following equation: EI2.1 = DF ·(Eon−farm + Eoff−farm) ECF The food energy content (ECF) of cooked corn, for example, is 960 kcal/kg [47] and the on-farm agriculture energy use (Eon−farm) for corn is 2 to 5 MJ/kg (calculated from [48]). The range represents a Fig. 1. Multi-dimensional interactions between energy demand and SDG targets and indicators. Source: Authors' illustration. more traditional farming method at one end and more energy intensive, modern farming at the other end. For simplicity, we have considered corn only. The off-farm agriculture energy use (Eoff−farm) for value chain including processing, storing and transportation, is about twice the Eon−farm [48] or approximately 4 to 10 MJ/kg. Using corn as an ap- proach, the energy intensity to end global undernourishment is about 564 to 1410 kJ cap−1·day−1 or approximately 205.86 to 514.65 MJ·cap−1 year−1. The energy requirement for food preparation and cooking is not included as it will be covered by the household and industrial energy sectors. Target 2.3. The target is to double the productivity and incomes of small farmers and measured with Indicator 2.3.1 - Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size. The small farmer land possession (LPSF) can be estimated as LPSF = AT · SSF SFT The estimation of the world total agricultural area (AT) is 4862.6 million ha in 2015 [49]. The share of the total land cultivated by small farmers (SSF) is 12%, which consist of about 2.5 billion full and part- time farmers (SFT) [50]. It gives us an LPSF estimate of 0.23 ha/farmer. The small farmer energy intensity (EI2.3), therefore, is EI2.3 = LPSF ·EF The average annual agriculture energy consumption (EF) ranges from 0 to 10 GJ/ha in most developing countries [51]. The EI2.3, therefore, will range from 0 to 2.33 GJ·farmer−1 year−1 in 2015. It is safe to assume that the additional energy required to double the small farmers' productivity will also be in the same range. It should be noted that doubling small farmers' productivity will feed the undernourished people in a country (Target 2.1). Therefore, Targets 2.1 and 2.3 will overlap to a certain degree. Target 2.4 is to ensure a sustainable food production system. It can be measured with Indicator 2.4.1 - Proportion of agricultural area under productive and sustainable agriculture. The productive and sustainable agriculture with low-input integrated farming consumes on average 26.85% less energy per hectare than the conventional one (based on wheat, maize, and soybean crops cultivated in Italy) [52]. In mathe- matical equation it gives: EISA = (100 − 26.85)% EICF With the global, conventional farming energy intensity (EICF) of about 8.4 GJ·ha−1 year−1 [48], the equation above gives us the pro- ductive and sustainable agriculture energy intensity (EISA) of about 6.1 GJ/ha. The energy saving (ES) potential of farming method con- version from conventional to productive and sustainable agriculture is ES = EICF − EISA = 2.3 GJ·ha−1 year−1 With the world population of 7.4 billion people [53] and the esti- mated global agricultural area of 4862.6 million ha in 2015 [49], the per capita agricultural area will be 0.66 ha/cap, and the energy saving potential will be 1.52 GJ·cap−1 year−1. 5.3. SDG 3 – good health and well-being Target 3.8. It is to provide universal health access, and its energy- related indicator is Indicator 3.8.1 - Coverage of essential health services. We assume that delivering essential health services means more people will visit health facilities. The energy intensity (EI3.8) can be calculated as EI3.8 EHC = V D The electrical energy consumption of health clinics (EHC) ranges from 5 to 30 kWh/day [54]. For non-electricity energy consumption, an estimation is provided by the African Solar Designs [55], in which LPG use is about 6 kg/month. Assuming 83 persons average daily visits per health clinic (VD) in Indonesian [56], the electricity energy intensities Table 2 The multi-tier framework of electricity access [66]. Tier Energy intensity Energy intensity Services (kWh·household−1·day−1) (kWh·household−1· year−1) 1 Min. 0.012 4.5 2 Min. 0.2 73 3 Min. 1 365 4 Min. 3.425 1250 5 Min. 8.219 3000 Task lighting, phone charging, radio Tier 1 + general lighting, fan, tv Tier 2 + food processing and washing machine Tier 3 + Refrigerator and iron Tier 4 + Air conditioning range from 22 to 132 kWh cap−1 year−1. The thermal energy intensity is only around 3 g LPG per person, annually. 5.4. SDG 4 – quality education Target 4.1. By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes. We lack data to estimate the global average figures, but similar studies in the national context are available. For example, the study by Wang [57] shows that Taiwan elementary, middle, and high schools operational energy intensities are about 289, 310, and 734 kWh·student−1 year−1, respectively. The embodied en- ergy of public school buildings (with three classrooms and an office) in Sri Lanka ranges from 224.97 to 483.47 GJ [58]. Assuming 20 students per classroom and 50 years of lifetime service, we found that the em- bodied energy intensities are 75 to 161.2 MJ·student−1 year−1. Target 4.2. By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education. Total operational energy (OE) in- tensities of pre-primary schools in Italy and Hong Kong are 86 and 119 kWh/m2, respectively [59]. However, due to the lack of data to convert them to per student unit, we assume that the operational and embodied energy intensities equal those of the primary school, which are 289 kWh·student−1 year−1 and 75–161.2 MJ·student−1 year−1, re- spectively [57,58]. Target 4.3. By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, in- cluding university. The average operational energy intensities in uni- versities: Korea = 210 kWh/m2 [60]; Griffith University Australia = 170 kWh/m2 [61]; and Taiwan = 1855 kWh·cap−1 year−1, ranging from 800 to 3000 kWh·student−1 year−1 [57]. The embodied energy intensity of a university building is assumed to be 20% of the opera- tional energy. 5.5. SDG 5 – gender equality Target 5.b. The target is to provide access to enabling technology for women. The energy relevant indicator is Indicator 5.b.1 - Proportion of individuals who own a mobile telephone, by sex. For regular uses, a smartphone with the battery energy (EB) of 1.2 Ah (about 16 kJ) per phone will last (th) for about 27 h [62]. The estimated energy require- ment for owning a mobile phone is EI5.b = EB 16 phkoJne 24 h 1 phone = · · th 27 h day person 5.19 MJ·cap−1 year−1. For different workloads, the battery life may Therefore, the EI5.b is estimated to be 14.22 kJ·cap−1·day−1 or range from 21 to 49 h [62]. The estimates, therefore, will range from 2.86 to 6.67 MJ·cap−1 year−1. 5.6. SDG 6 – clean water and sanitation Target 6.1 is related to achieving universal access to safe and af- fordable drinking water and measured by Indicator 6.1.1 - Proportion of population using safely managed drinking water services. A study of the urban water supply energy use in China shows that the (electricity) energy intensity for drinking water processing is 0.29 kWh/m3, which is equivalent to 33.2 kWh·cap−1· year−1 [63]. A similar study in India reveals that the energy intensity is 0.3 kWh/m3 or 18 kWh·cap−1· year−1 [64]. Target 6.3 is to improve water quality, which is measured by Indicator 6.3.1 - Proportion of wastewater safely treated. The electricity energy intensities of urban wastewater treatment plants in China range from 0.95 to 1.25 kWh/m3 [65] for plants' capacities between 10,000 m3/day to 80,000 m3/day. India's municipal wastewater (elec- trical) energy intensity ranges from 0.05 kWh/m3 to 0.15 kWh/m3 or about 0.6 to 3.8 kWh·cap−1· year−1 [64]. 5.7. SDG 7 – affordable and clean energy Target 7.1 is to achieve universal access to sustainable energy. Energy access includes electricity access and clean cooking fuel access, and the target is represented by two indicators: Indicator 7.1.1 - Proportion of population with access to electricity and Indicator 7.1.2 - Proportion of population with primary reliance on clean fuels and tech- nology. The energy intensity for the former indicator (EI7.1.1) can be estimated using the World Bank's multi-tier framework for energy ac- cess [66]. The framework divides household electricity uses into five tiers, as shown in Table 2. The higher the tier, the better the service (regarding capacity, services, duration of availability, reliability, and quality). At least Tier 3 electricity access should be provided to satisfy basic human needs for lighting, phone charging, radio, fan, television, food processing, and washing machine [66]. On the other hand, the energy intensity for cooking (EI7.1.2) in the developing countries is about 22 kg·cap−1 year−1 of LPG [26] or about 996 MJ·cap−1 year−1. Another study suggests that EI7.1.2 is approximately 40 kg of oil equivalent or 1674.72 MJ·cap−1 year−1 [67]. Target 7.2 is to increase the renewable energy share. The indicator is the renewable energy share in the total final energy consumption (Indicator 7.2.1). The global renewable energy consumption in 2015 was 18.05% of the total final energy consumption [68]. The target is to increase it substantially, which lacks a precise number. A country would, there- fore, need to select a share that could be considered as a substantial increase. Target 7.3 is to double the global energy efficiency, measured by the Indicator 7.3.1 - Energy intensity measured in terms of primary energy and GDP. The global energy intensity in 2015 (EI2015) was 5.13 MJ/$2011 PPP GDP [68]. According to the IEA and World Bank, the SDG target (EI7.3) is to achieve the energy intensity growth of -2.6% by 2030 [22], which is equivalent to a global energy intensity of 3.58 MJ/$2011 PPP GDP by 2030. Our calculation using the World Bank data [68] shows that the annual energy intensity growth during the 2001–2015 period was about -1.58%. Assuming the same annual growth for the next 15 years under the BAU, the energy intensity (EIBAU2030) will be about 4.04 MJ/$2011 PPP. 5.8. SDG 8 – decent work and economic growth Target 8.1 is to maintain the per capita economic growth. GDP increases are usually associated with increases in energy consumption. However, sustaining the same per capita economic growth for the next 15 years means doing business as usual. Furthermore, the energy in- tensities of GDP (EI2015 and EI7.3), in the MJ/GDP unit, have been de- termined under Target 7.3. It means that calculating the total energy consumption in year x (Ex) is as simple as Ex = EIx · GDPx Target 8.1 is related to Target 7.3, and the energy equivalence of those targets should be combined. A simplified calculation of the energy correspondence of those targets is explained below. The 2030 total energy equivalence of the implementation of Target 8.1 without con- sidering the efficiency measure (Target 7.3) will be E8.1 = EIBAU2030 ·GDP8.1 GDP8.1 is the GDP of Target 8.1, which equals GDPBAU2030. Since GDP8.1 equals GDPBAU2030, therefore E8.1 equals EBAU2030. Target 7.3 requires that the energy intensity is reduced to EI7.3 by 2030. Therefore, the energy equivalence of the implementation of Targets 8.3 and 7.3 (E8.1+7.3) will be E8.1+7.3 = EI7.3 · GDP8.1 The 2030 energy reduction potential (E7.3) will be E7.3 = (EIBAU 2030 − EI7.3) · GDP8.1 or E7.3 = E8.1 − E8.1+7.3 Based on the World Bank data [69], the world GDPs in 2001 and 2015 are 10,453 and 14,778 $ (2011 PPP) per capita, respectively, giving an annual GDP growth rate of 2.5%. Sustaining the same growth rate (Target 8.1, which is also the BAU) gives GDP8.1 of 21,416 $ (2011 PPP) per capita by 2030. Solving for E8.1 and E8.1+7.3 gives 86,529 and 76,719 MJ per capita of global primary energy supply under the BAU and SDGs scenarios, respectively. Therefore, successful implementa- tions of Target 7.3 will potentially save the world almost 9810 MJ per capita by 2030. Note that the energy calculated above is the primary energy supply. Its final energy consumption equivalence will depend on the national context of energy conversion technologies. The global conversion effi- ciency is roughly 68.76% in 2015, which is based on the global total primary energy supply (TPES) and TFEC of 13,647 and 9384 million tons of oil equivalent (MTOE), respectively [70]. Assuming 70% effi- ciency by 2030, the TFEC equivalences of E8.1 and E8.1+7.3 will be around 60,570 and 53,704 MJ/capita, respectively. The final energy reduction potential will be about 6.867 MJ/capita by 2030. Caution should be exercised while using equations for this target as the use of GDP growth rate in the BAU scenario would mean that the impact of GDP on energy demand has already been included under the BAU scenario. Therefore, the modality of estimating effects of Target 8.1 will depend on how GDP growth rate is considered in the national energy planning. 5.9. SDG 9 – industry, innovation, and infrastructure Target 9.1. The target is to provide access to quality infrastructure. Its energy-related indicators are Indicator 9.1.1 - Proportion of the rural population who live within 2 km of an all-season road and Indicator 9.1.2 - Passenger and freight volumes, by mode of transport. Calculating the energy required to ensure people live within 2 km of a reliable road is complicated. We need to estimate the proportion of the rural population with road access, widely known as the rural access index (RAI), by understanding the population distribution (where people live), road networks (the location of the roads), and the road quality [71]. Moreover, the Inter-agency and Expert Group on SDG Indicators of the United Nations classifies Indicator 9.1.1 a Tier 3 indicator [72]. Tier 3 is the lowest level of the classification indicating that the methodology and standards of the indicator are under devel- opment or testing. The literature shows that the energy requirement of constructing a single carriageway road (EI9.1.1) is 3.3–11.7 TJ/km, which is based on studies in European countries [73]. Another study shows that the average energy requirement for asphalt road construction, main- tenance, and operation is about 580 GJ·km−1 year−1 (hot method, 13 m wide) [74]. To convert it to a per-capita unit, the RAI needs to be de- termined. The index will also give us the number of the population without the access. There is no easy way to translate this number to a road requirement in km per capita. In the meantime, the world is still waiting for the new methods of measuring rural access. An example of the energy quantification data for the Indicator 9.1.2 is provided by the Deutsche Bahn [75]: Rail passenger EI = 0.38 to 0.98 MJ/pass-km; road passenger EI (bus) = 1.19–1.3 MJ/pass-km; rail freight EI = 0.35 MJ/ton-km; road freight EI = 1.38 MJ/ton-km; air freight EI = 10.25 MJ/ton-km. We lack data of global energy intensities of different modes of transport and methods of converting them to per capita energy consumption. However, calculating Indicator 9.1.2 based energy demand in the national context will be possible as long as the national target is set in the standard pass-km and ton-km units and the EIs are known. Target 9.c is to provide access to communications and information technology, which can be assessed with Indicator 9.c.1 - Proportion of population covered by a mobile network, by technology. Assuming 300 users/km2, the wireless network power intensities (PW) are approxi- mately 18, 27, and 68 W/user for the LTE (4 G), WiMAX, and HSPA (3 G) technologies, respectively [76]. The energy intensity is EI9.c.1 = PW ·t For the networks with non-stop operating hours (t) of 8760 h a year, the energy intensity for the LTE, WiMAX, and HSPA technologies are 157.68, 236.52, and 595.68 kWh·user−1 year−1, respectively, which are equivalent to 567.65, 851.47, and 2144.45 MJ·user−1 year−1. 5.10. SDG 11 – sustainable cities and communities Target 11.1 is to ensure access to adequate housing. The amount of energy required to provide adequate housing varies from country to country. The embodied energy intensities of multi-story, two-story, and single-story houses in India are estimated to be 4.32, 4.81, and 5.23 GJ/ m2, respectively [77]. Assuming a floor surface area of 10 m2/person for adequate housing [78] and 50 years of lifetime services, the energy intensities (EI11.1) are 864, 962, and 1046 MJ·cap−1 year−1. The housing operational energy requirement for lighting, appliances, and cooking is omitted as it has been covered by Target 7.1. Target 11.2 is to provide access to a sustainable urban transport system and can be measured by Indicator 11.2.1 - Proportion of popu- lation that has convenient access to public transport, by sex, age and persons with disabilities. Convenient access to public transport (PT) can be de- fined as a waiting time of less than 15 min at a bus stop less than 500 m away from home [79]. It can also mean a station with a convenient park and ride facility and a travel time of less than 30 min to destination. Increasing the proportion of the population with convenient access to PT means providing more bus stops and stations and increasing the frequency of the arrival and departure of buses and other PT, therefore increasing the energy use. We choose buses to represent public trans- port. The average energy intensity of traveling by bus (EIAverage) in low income cities is 0.59 MJ/passenger-km [80]. For simplicity, the addi- tional energy requirement to upgrade the services to the convenient level (EI11.2) can be assumed to range from zero to 0.59 MJ/passenger- km. Once the public transport is convenient, a shift from private car to public transport is expected, which presumably will reduce energy demand in the transport sector. It is the second-order interaction be- tween energy and Target 11.2. This study only focusses on the first- order interaction. Target 11.6. The target is to reduce cities environmental impact, which is to be measured with Indicator 11.6.1 - Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities. A study in Austria shows that the energy intensity of Target 11.6 (EI11.6) is 529.75–537.88 MJ·cap−1· year−1 or 1657 to 1682 MJ/t of municipal solid waste (MSW), which is consumed during waste collection and treatment processes including transportation, collection containers, and treatment of bio-waste, bulky waste and residual waste [81]. 5.11. SDG 12 – responsible consumption and production Target 12.3 - By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses. Since food losses and waste in de- veloped countries mostly related to consumer behaviors and pre- ferences, which are not associated with energy, we focus on the food loss in the developing world because of their poor harvesting methods, inadequate storage facilities and transportation infrastructure, and limited processing and packaging (retailing) technologies [82]. The energy intensity for achieving Target 12.3 (EI12.3) can be estimated as EI12.3 = (ECStorage + ECRetailing)·LHalf The energy requirement for the transportation infrastructure is not considered here as it has been covered by Target 9.1. Food losses are about 114 and 159 kg·cap−1 year−1 in South/Southeast Asia and Sub- Saharan Africa, respectively (calculated from [83]). The target of halving the losses (LHalf) means 57 and 79.5 kg·cap−1 year−1. Moder- nizing post harvesting food processes in developing countries includes the energy consumption for storage (ECStorage) and energy consumption for retailing (ECRetailing) of about 2 MJ/kg and 2.5 MJ/kg, respectively [48]. Using the equation, the energy intensity will approximately be 256.5 and 357.75 MJ·cap−1 year−1 in South/Southeast Asia and Sub- Saharan Africa, respectively. Target 12.5 is to reduce waste generation, which is to be measured with Indicator 12.5.1 - National recycling rate, tons of material recycled. The energy requirement for waste collection and treatment at waste management facilities is between 529.75 and 537.88 MJ·cap−1· year−1 (1657 to 1682 MJ/t of MSW) [81], as described in Target 11.6. How- ever, since recycling reduces indirectly raw materials to be extracted, processed, and transported, there is a net energy saving potential (ES12.5.1) of 461.50–523.25 MJ·cap−1 year−1 (1.64 GJ/t of MSW) [81,84]. Industrial waste is not considered, assuming that it has less waste reduction opportunity. Note that if the energy requirement for waste collection and treatment has been included in Target 11.6, the energy intensity of this target (EI12.5) is -1001 to -1,053 MJ·cap−1 year−1 (-3.13 to -3.29 GJ/t). 5.12. SDG 13 – climate action Target 13.1 - Strengthen resilience and adaptive capacity to climate-re- lated hazards and natural disasters in all countries. The embodied primary energy required to build a temporary, post-disaster container house of 4 occupants is approximately 82.6–226.7 GJ [85]. The primary energy intensity, therefore, ranges 20.65–56.675 GJ/cap. Assuming 70% pri- mary to final energy conversion factor and 20 years of lifetime services, the final energy intensity (EI13.1) is 722.5 to 1983.63 MJ·cap−1 year−1. The operational energy requirement (for lighting, comfort, and appli- ance uses) is omitted, as it has been included under the normal con- dition (before the disaster). 5.13. SDG 17 – partnerships for the goals Target 17.6 is to enhance access to science, technology, and in- novation. Its energy-related indicator is Indicator 17.6.2 - Fixed Internet broadband subscriptions per 100 inhabitants, by speed. The power re- quirement of an internet infrastructure with a shared passive optical network (PON) connection serving an access rate of 25 Mbps (PPON) is 9–11 watt/customer [86]. Assuming 8760 h of continuous service a year, the annual energy intensity of the target is EI17.6 = PPON ·8760 It gives 78.84–96.36 kWh/customer (or 283.82–346.9 MJ/cus- tomer), annually. Target 17.8 is to enhance the use of enabling technology, which is to be measured by Indicator 17.8.1 - Proportion of individuals using the Internet. The energy intensity for the target can be estimated as EI17.8 = PPC ·tNet The time spent on the internet for medium users (tNet) is 20 to 60min/day [87]. The power requirement to access the internet (PPC) using laptop and desktop computers ranges from 12 to 169W/user [88]. Therefore, the energy intensity (EI17.8.1) ranges from 4 to 169 Wh·user−1·day−1 or 5.3 to 222.1MJ·user−1year−1. Applying a wider time span of 1 to 620min for light to heavy users [87], the energy intensity ranges from 0.26 to 2295MJ·user−1year−1. 6. Results and discussion Table 3 provides an overview of the energy required to fulfill each SDG target. Twenty-five targets previously identified are translated into energy demand. Target 1.4 is not included since most of the other targets will contribute to it. Targets 2.4, 7.3, and 12.5 have negative values, which indicate that those targets will reduce energy consump- tion. Target 7.2 may affect primary energy supply and the fuel shares, but it does not increase or decrease final energy uses. Energy equiva- lence of Target 8.1 is the overall average energy requirement per capita. It was calculated together with Target 7.3 to provide the energy re- duction potential under the implementation of energy efficiency mea- sures. The quantification process applied simple algebraic methods, and the results at the country level may vary depending on the country data. A major implication of this procedure is that it relies on many as- sumptions, and the credibility of the estimates depend on the reliability of assumptions and the quality of data and references. Therefore, Table 3 also provides an assessment of our levels of confidence to the assumptions and references. Low, medium and high are the three levels of confidence we use to assess assumptions and references. The com- bination of assumptions and references levels of confidence determines the overall confidence level of the outcomes, which applies five levels of confidence: very low, low, medium, high, and very high. Overall, two targets (3.8 and 11.2) have low confidence levels due to low confidence levels on the assumption side. For example, in esti- mating the global energy requirement to ensure health access (Target 3.8), we lack data of the global average energy demand per health clinic visit and total visits per unit of time. Our assumptions using estimates from Africa and Indonesia studies lack confidence in the accuracy of the assumptions. A similar reason applies to assumptions of Target 11.2. However, the confidence level of the assumptions in the national con- text can be improved by applying estimates taken from studies con- ducted locally. On the other hand, we are highly confident with the estimates of Targets 5.b and 17.8. Assuming wide ranges of estimates taken from reputable sources increases the confidence level of the assumptions. On the references side, evidence from peer-reviewed studies convinces us that the data are highly credible. Our confidence level is very high when the confidence levels of both assumptions and references are high. Twenty-two targets, sharing the same unit, are comparable. Targets 8.1, 9.1, and 11.2 are excluded for the reasons previously explained: calculated together with another target (Target 8.1), weak indicator Table 3 Summary of total energy demand associated with the SDG targets. SDG Descriptions Energy demand Units Assumptions Data and references Overall targets (confidence) (confidence) Confidence 2.1 2.3 2.4 3.8 4.1 4.2 4.3 209 5.b 6.1 6.3 7.1 7.2 7.3 8.1 9.1.1 9.1.2 Undernourishment Food production Sustainable agriculture Access to health care Primary & secondary education Pre-primary education Tertiary education Access to mobile phone Access to drinking water Water quality Access to energy Renewable energy share Energy efficiency Sustainable economic growth Access to road Transportation infrastructure 205.86 to MJ·cap −1·year−1 514.65 0 to 2334 MJ·farmer−1·year−1 −1,520 to 0 MJ·cap −1·year−1 79.2 to 475.2 MJ·cap−1·year−1 (electricity) 0.147 MJ·cap−1·year−1 (LPG) 587 to 1404 MJ·student−1·year−1 (elementary school) (OE) 990 to 2938 MJ·student−1·year−1 (junior high school) (OE) 1890 to 3987 MJ·student−1·year−1 (senior high school) (OE) 75 to 161.2 (EE) MJ·student −1·year −1 587 to 1,404 MJ·student−1·year−1 (OE) 75 to 161.2 (EE) 2880 to 10,800 MJ·student −1·year−1 (OE) 576 to 2160 (EE) 2.86 to 6.67 MJ·cap −1·year−1 64.8 to 119.52 MJ·cap−1·year−1 2.16 to 13.68 MJ·cap−1·year−1 Tier 3: 328.5 to MJ·cap −1·year−1 (electricity) 1,125 996 to 1674.72 MJ·cap −1·year−1 (cooking) The target does not change the final energy consumption Corn to replace food; the off-farm energy use is twice the on-farm [18,47,48] (Medium) (Medium) Average energy consumption in developing countries is used; overlap [49,50,51] between Targets 2.1 and 2.3 (Medium) (Medium) Based on wheat, maize, and soybean crops cultivated in Italy [48,49,52,53] (Medium) (Medium) Based on energy estimate intended for Africa; using average visit data from [54,55,56] Indonesia (Medium) (Low) Based on Taiwan’s school energy intensity and study done in Sri Lanka; 20 [57,58] students per class, 50 years lifetime service (High) (Medium) Based on the elementary schools EI (Low) Based on studies in Taiwan and the US (Medium) [57,58,59] (High) [57,60,61] (High) Mobile phone batteries are recharged every 21 to 49 hours on average [62] (High) (High) Based on studies in China and India [63,64] (Medium) (High) Based on studies in China and India [64,65] (Medium) (High) Based on the World Bank framework for energy access; Tier 3 is adopted; 4 [26,66,67] persons per household (High) (Medium) Based on the IEA and World Bank recommendation (Medium) −6,867 to 0 MJ·cap−1 in 2030 MJ·cap−1 in 2030 The targets are calculated together; the annual EI and GDP growths under [22,68,69,70] 53,704 to the BAU are the same as those of the past; the primary to final energy (High) 60,570 (this is the overall demand calculated together with conversion factor is 70% by 2030. Target 7.3. See the discussion section) (Medium) 3.3 to 11.7 106 MJ·km−1 This indicator is under development; the figures are based on studies in [71,72,73,74] European countries. (Medium) (Medium) Rail pass.: 0.38 MJ·pass-km−1 possible as long as the targets are set in MJ·pass-km−1 and MJ·ton-km−1 and (Medium) They are based on studies in Germany; calculating energy requirement is [75] to 0.98 Bus: 1.19 to 1.3 the EIs are known. Rail freight: MJ·ton-km−1 (Medium) 0.35 Road freight: 1.38 Medium Medium Medium Low High Medium High Very high High High High High Medium Medium (continued on next page) W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 Table 3 (continued) SDG Descriptions Energy demand Units Assumptions Data and references Overall targets (confidence) (confidence) Confidence 9.c 11.1 11.2 11.6 12.3 12.5 13.1 17.6 17.8 210 Access to ICT Access to housing Access to public transport Solid waste management Food waste &losses Waste reduction Resilience to disasters Access to science Access to internet LTE (4 G): 567.65 WiMAX: 851.47 HSPA (3 G): 2144.45 864 to 1046 (EE) 0 to 0.59 MJ·user−1·year−1 300 mobile network users/km2; nonstop operation of 8760 h/year. (Medium) [76] (High) MJ·cap−1·year−1 Based on a test case study on Indian housing practices; floor area of 10 m2/ [77,78] person; the OE is covered by Target 7.1. (High) (Medium) MJ·pass-km−1 Busses are to represent public transport (PT); the average EI is based on [79,80] studies in low-income cities; the EI to upgrade to the convenience level is (Medium) twice the EI of the inconvenience PT (Low) 529.75 to MJ·cap−1·year−1 Based on a study in Austria [81] 537.88 (Medium) (High) 256.5 to 357.75 MJ·cap−1·year−1 Consider only food losses; data of the developing countries. [48,82,83] (Medium) (Medium) −1,001 to MJ·cap−1·year−1 Industrial waste is not considered; based on a study in Austria [81,84] −1053 (Medium) (High) 722.5 to MJ·cap−1·year−1 Based on a study in Turkey; 70% primary to final energy conversion factor. [85] 1983.63 (Medium) (High) 283.82 to 346.9 MJ·customer −1·year−1 Nonstop operational hours of 8760 h/year; shared passive optical network [86] (PON) connection serving an access rate of 25 Mbps (High) −1·year−1 (Medium) 0.26 to 2,295 MJ·user 1-620 minutes/day internet use; internet access using laptop or desktop [87,88] computers (High) (High) High High Low High Medium High High High Very high W.G. Santika et al. Energy

Research & Social Science 50 (2019) 201–214 Fig. 2. Additional energy requirement under the SDGs regime. Blue and green bars indicate energy demand and reduction potential, respectively. Source: Authors' illustration. and insufficient data (Targets 9.1 and 11.2). Fig. 2 illustrates targets associated with high and low energy demand and reduction potential. Mainstreaming Target 4.3 (access to tertiary education) will consume energy the most per person. On the other hand, providing access to mobile phones (Target 5.b), clean water (Targets 6.1 and 6.3) and internet (Target 17.8, should be combined with Target 17.6, however) require relatively a minimal amount of energy. In contrast, successful implementation of Target 7.3 (energy efficiency) will reduce energy demand dramatically considering that its high energy reduction potential per capita will be multiplied by the whole population. Indeed, a study comparing the effects of Targets 7.1 (providing clean energy access) and 7.3 on the residential sector energy demand in Indonesia shows that energy efficiency measures may cancel out the additional energy required to ensure clean energy access for everyone [89]. Targets 2.1 (food access) seems to consume less energy per person than Target 2.3 (small farmers productivity). The upper limits of E2.1 and E2.3 are approximately 514.65 MJ·cap−1 year−1 and 2334 GJ·farmer−1 year−1, respectively. However, E2.3 is the energy demand per farmer to produce food. Considering land possession of only 0.23 ha per farmer (subsection 5.2) and a modest corn production of 1721 kg/ha [90], each farmer will produce around 396 kg of corn per year, which is enough to feed eleven undernourished people (Target 2.1) whose annual food deficit is equivalent to 34 kg of cooked corn per capita (calculated from subsection 5.2). In order to ensure more food for everyone, addressing Target 2.3 may require less energy per capita than Target 2.1. Similarly, addressing Target 12.3 (halving food losses) will potentially consume less energy per capita than implementing Target 2.1 if the objective is to provide more food. Successful endeavors in halving the food losses in Sub-Saharan Africa, for instance, may save about 79.5 kg·cap−1 year−1 of food (sub-section 5.11). Meanwhile, addressing food deficit in the region (Target 2.1) may produce only about 49.9 kg·cap−1 year−1 of food. In other words, consuming a comparable amount of energy, Target 12.3 may save more food than Target 2.1 can produce. In the energy perspective, (developing) countries can start with Targets 6.1 (clean water access), 6.3 (water quality improvement), 2.3 (small farmers production), 12.3 (food losses reduction), 2.4 (sustainable food production systems), 3.8 (health care access), 7.1, 72, and 7.3 (energy access, shares, and efficiency), 4.2 (preschool education), 4.1 (primary and secondary education), 5.b, 9.c, 17.6 and 17.8 (communication and internet infrastructure and access), 11.6 and 12.5 (solid waste management and recycling). Consuming relatively more energy per capita, the rest of the targets will be the next priority. Using the interlinkages map of SDGs targets with first-order connections to energy, this paper has developed a framework to quantify additional energy requirement (compared to business-as-usual) per unit of activities for the interlinked 25 targets. A set of examples have been proposed that can be used by national policymakers to estimate the energy requirement for a country using their country-specific data into these equations. To illustrate how this process will work at a national level, we provide two examples below. Ending hunger in a developing country such as Indonesia means more energy demand to produce enough food for nearly 20 million people who were undernourished in 2015 [91]. We merely assume that the food supply at the time was not enough to satisfy demand, and the deficit will be produced domestically. With a depth of food deficit of 51 kcal·cap−1·day−1 during the same year [18], the total food deficit in Indonesia was about 365,232 Gcal. According to the Ministry of Agriculture, Indonesian diets mostly lack meats, roots and tubers, and fruits and vegetables [92,93]. The caloric requirements of meats for a balanced diet is twice as much as that of roots and tubers or fruits and vegetables [93]. For simplicity, meats, roots and tubers, and fruit and vegetables are converted to equivalent amounts of poultry, potatoes, and tomatoes, respectively. Using a similar procedure for Target 2.1, our calculation reveals that approximately 11.76 PJ of additional energy will be needed to produce enough food for everyone in Indonesia by 2030. It equates to an energy intensity of 599.5 MJ·cap−1 year−1, slightly higher than the global EI2.1 of 514.65 MJ·cap−1 year−1 estimated in Section 5. The difference is related to the use of more detailed data specific to Indonesia including the depth of food deficit (51 vs. 90.25 kcal·cap−1·day−1) and the food assumed to cover the deficit. Another example can be taken from Target 4.1 about universal education access for all girls and boys. The minimum elementary school's floor to student ratio in Indonesia, according to the Ministry of National Education Regulation No. 24/2007, is 3.3 m2/student. The intensity of energy consumption of efficient government office buildings (without air conditioning) in Indonesia is expected to be 5.6 kWh·m−2·month-1 or less, which is based on the Ministry of Energy and Mineral Resources Regulation No 13/2012. Therefore, energy consumption should be approximately 221.76 kWh·student-1 year-1 or 798.33 MJ·student-1 year-1. It is lower than the average consumption of 1040 MJ·student-1 year-1 shown in subsection 5.4. The difference is partly due to the assumption of building without air conditioning that we chose. Assuming energy consumption of 8.5 kW h·m-2·month-1 regulated for air-conditioned government buildings, we found that the energy consumption will be 1212 MJ·student-1 year-1, which is now higher than the average figure. These two examples demonstrate that choosing the right assumption is a key to accurate estimation. Some quantification figures are directly adopted from scientific studies, such as Target 5.b (access to mobile phones for women). Daily energy requirement to charge batteries for smartphones of normal uses can be assumed similar globally. For some other targets, we lack data, as in Target 6.1 (access to clean water). In this case, we select figures provided by studies conducted in India and China. The energy required to produce a cubic meter clean water is comparable: 0.29 kWh in China [63] and 0.3 kWh in India [64]. Interestingly, when they are converted to per capita consumption, the energy requirement differs significantly: 33.2 and 18 kWh·cap−1· year−1 in China and India, respectively [63,64]. The difference is mainly due to the per capita water consumption contrast between China and India. Some overlapping or double counting might be inevitable. For instance, providing Tier 2, or higher, electricity access to a house (Target 7.1) surely will include an assumption of electricity consumption of 200 Wh·day−1·household−1, or higher, for lighting, television, fan, and phone charging. Target 7.1 will cover Target 5.b (access to mobile phones for everyone) for households provided with electricity access during the 2015–2030 period. However, for houses electrified before the SDGs implementation, adding mobile phones to them will require additional energy. Similarly, doubling the productivity of small farmers (Target 2.3) and halving the food waste and losses (Target 12.3) will add and save more food to feed the undernourished people (Target 2.1). However, it will be true if undernourishment is related to the issue of food availability, but not affordability. On the other hand, sustaining the global GDP growth (Target 8.1) only (without combining it with Target 7.3) should not be considered as an ambitious target. Maintaining something that has already been achieved is just doing business as usual. Therefore, the energy equivalence of Target 8.1 (E8.1) is the total energy demand under the BAU. The total energy demand under the SDGs regime is the energy demand associated with the combination of Targets 8.1 and 7.3 (E8.1+7.3), which will be lower than E8.1. Our suggestion is to consider the energy equivalence of Target 8.1, together with Target 7.3 (doubling the global energy efficiency), as a benchmark for local/national energy consumption. As stated in sub-section 5.8, the energy consumption benchmark will be E8.1+7.3 = EI7.3·GDP8.1 It means that the global average energy consumption in 2030 under the SDGs scenario should not be higher than 76,719 MJ·cap−1· year−1 of primary energy or 53,704 MJ·cap−1· year−1 of final energy (sub-section 5.8). Therefore, E8.1 and E8.1+7.3 should not be added with the energy demand of the other targets when estimating the additional energy requirement under the SDGs regime. We also recommend that the primary energy consumption benchmark of 76,719 MJ·cap−1· year−1 will be one of the prioritized SDG targets for the developed nations in order to reduce emissions and inequality among countries. The average primary energy consumption in the high-income countries was 192,765 MJ/cap in 2015 [94], more than 2.5 times the proposed benchmark. Meanwhile, the average primary energy consumption in the low and middle-income countries was only 55,467 MJ/cap in 2014 [94]. It is consistent with Steinberger and Roberts' findings [4] suggesting that energy requirements associated with high human development decrease over time and, beyond 2010, high human development is attainable with primary energy consumption of less than 70,000 MJ/cap. The benchmark is higher than the 2000-watt society target [28]. The energy consumption target of the society is 2000 W/cap, in which 2000 W equals 2 kWh/h or 63,072 MJ/ year. 7. Conclusions The analysis of interlinkages between energy and SDG targets revealed a complex interaction involving synergies and trade-offs that would significantly impact future energy scenarios at national and local levels. This paper developed a process to estimate the additional energy demand to be anticipated and its consequences to the energy supply side in comparison to the baseline scenario, which is essential to forecast local/national energy demand under the SDGs scenario. Consequently, it bridged the gap between the wide recognition in the scientific community about the need to incorporating the impacts of SDG targets on energy due to interlinkages and the lack of a mechanism on how to practically estimate the changes in energy demand in re- sponse to the interlinkages. It has been done by quantifying energy demand for each of the identified direct links and developing a uni- versal computation method to allow estimation at a national level. While three targets would contribute to the reduction in energy de- mand, the net demand has been found to be positive. This study suggests that policymakers can no longer work in silos and develop energy plans based on assumptions from the energy sector only and try to achieve SDG 7, but they also need to incorporate the additional energy demand that would be necessary to accomplish other SDGs. Each country has different starting points and priorities that make the implementation of the SDGs in local and national develop- ment planning unique for that country. Therefore, different goals, tar- gets, and priorities need to be set to match national resources and capabilities. We suggest that policymakers first work with re- presentatives from all sectors and identify target levels of these 25 SDG targets and then use the methods to estimate additional energy demand required to achieve those targets. The results then can be added to the baseline energy demand to obtain an SDG-responsive energy scenario. The breadth of interconnection found in this paper as well as in other literature is highly complex and has multi-dimensional linkages. As the first research of its kind and due to the lack of sufficient data, this paper has considered only the first-order connections. We recommend that further research is carried out to extend this framework to enable incorporation of subsequent orders of linkages. We also recommend further research to incorporate the Nationally Determined Contributions (NDCs) under the Paris Agreement into this framework to capture the emission reduction targets and appropriately cover the supply side of the energy planning.

Acknowledgments The authors wish to thank the School of Engineering and Information Technology, Murdoch University, Australia for providing the research grant to pursue this research. The research is also sup- ported by the Ministry of Research, Technology, and Higher Education and the Ministry of Finance of the Republic of Indonesia through the Indonesia Lecturer Scholarship (BUDI-LPDP) granted to the first author. Appreciation is also extended to Mr. Thiyagarajan Velumail for his guidance with this research.

Appendix A. Supplementary data Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.erss.2018.11.016.

References [1] UNDP, UNDP Support to the Implementation of Sustainable Development Goal 7: Affordable and Clean Energy, Available at: United Nations Development Programme, New York, 2016http://www.undp.org/content/dam/undp/library/ Climate and Disaster Resilience/7 Clean Energy-Feb 2017. pdf. [2] D.M. Martinez, B.W. Ebenhack, Understanding the role of energy consumption in human development through the use of saturation phenomena, Energy Policy 36 (4) (2008) 1430–1435. [3] J.C. Steckel, R.J. Brecha, M. Jakob, J. Strefler, G. Luderer, Development without energy? Assessing future scenarios of energy consumption in developing countries, Ecol. Econ. 90 (2013) 53–67. [4] J.K. Steinberger, J.T. Roberts, From constraint to sufficiency: the decoupling of energy and carbon from human needs, 1975–2005, Ecol. Econ. 70 (2) (2010) 425–433. [5] A. Mazur, Does increasing energy or electricity consumption improve quality of life in industrial nations? Energy Policy 39 (5) (2011) 2568–2572. [6] S. Fukuda-Parr, From the Millennium Development Goals to the Sustainable Development Goals: shifts in purpose, concept, and politics of global goal setting for development, Gend. Dev. 24 (1) (2016) 43–52. [7] J. Sachs, G. Schmidt-Traub, C. Kroll, G. Lafortune, G. Fuller, SDG Index and Dashboards Report, Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN), New York, 2018. [8] G. Schmidt-Traub, C. Kroll, K. Teksoz, D. Durand-Delacre, J.D. Sachs, National baselines for the Sustainable Development Goals assessed in the SDG index and dashboards, Nat. Geosci. 10 (8) (2017) 547. [9] A. Bhardwaj, M. Joshi, R. Khosla, N.K. Dubash, More priorities, more problems? Decision-making with multiple energy, development and climate objectives, Energy Res. Soc. Sci. 49 (2019) 143–157. [10] D. Le Blanc, Towards integration at last? The Sustainable Development Goals as a network of targets, Sustain. Dev. 23 (3) (2015) 176–187. [11] N. Weitz, M. Nilsson, M. Davis, A nexus approach to the post-2015 agenda: for- mulating integrated water, energy, and food SDGs, Sais Rev. 34 (2) (2014) 13. [12] ICSU, Guide to SDG Interactions: From Science to Implementation, International Council for Science (ICSU), Paris, 2017. [13] F.F. Nerini, et al., Mapping synergies and trade-offs between energy and the Sustainable Development Goals, Nat. Energy 3 (1) (2018) 10. [14] D.L. McCollum, et al., Connecting the Sustainable Development Goals by their en- ergy inter-linkages, Environ. Res. Lett. 13 (3) (2018) p. 033006. [15] D. McCollum, et al., Connecting the Sustainable Development Goals by their energy inter-linkages, IIASA Working Paper, The International Institute for Applied Systems Analysis, Laxenburg, 2017 Available at: http://pure.iiasa.ac.at/14567/. [16] UNDP, Sustainable Development Goals, Available at: (2017) Accessed 19 April 2018 http://www.undp.org/content/undp/en/home/sustainable-development- goals.html. [17] FAO, IFAD, WFP, The State of food insecurity in the world 2015, Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress (Food and Agriculture Organization Publications), FAO, Rome, 2015. [18] World Bank, Depth of the Food Deficit (kilocalories Per Person Per Day), Available at: (2017) Accessed 27 November 2017 https://data.worldbank.org/indicator/SN. ITK.DFCT?locations=ZG-1W. [19] WHO and UNICEF, Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines, World Health Organization (WHO) and the United Nations Children’s Fund (UNICEF), Geneva, 2017. [20] UN-OHCHR, UN-HABITAT, and WHO, The right to water, Fact Sheet No. 35, United Nations Office of the High Commissioner for Human Rights, Geneva, 2010 Available at: http://www.ohchr.org/Documents/Publications/FactSheet35en.pdf. [21] M. Bhatia, N. Angelou, Beyond Connections: Energy Access Redefined, The World Bank, Washington DC, 2015. [22] IEA, the World Bank, Sustainable Energy for All 2017: Progress Towards Sustainable Energy, Available at: World Bank, Washington, DC, 2017http:// seforall.org/sites/default/files/eegp17-01_gtf_full_report_final_for_web_posting_ 0402.pdf. [23] IEA, World Energy Outlook 2016, International Energy Agency, Paris, 2016. [24] IEA, the World Bank, Sustainable Energy for All 2013-2014: Global Tracking Framework Report, World Bank, Washington, DC, 2014. [25] IEA, the World Bank, Sustainable Energy for All 2015—Progress Toward Sustainable Energy, World Bank, Washington DC, 2015. [26] IEA, World Energy Outlook 2006 - Excerpt - Energy for Cooking in Developing, Available at: IEA, 2006, https://www.iea.org/publications/freepublications/ publication/cooking.pdf. [27] J.M. Cullen, J.M. Allwood, E.H. Borgstein, Reducing energy demand: what are the practical limits? Environ. Sci. Technol. 45 (4) (2011) 1711–1718. [28] D. Spreng, Distribution of energy consumption and the 2000 W/capita target, Energy Policy 33 (15) (2005) 1905–1911. [29] O. Akizu-Gardoki, Decoupling between human development and energy con- sumption within footprint accounts, J. Clean. Prod. 202 (2018) 1145–1157. [30] R.U. Ayres, H. Turton, T. Casten, Energy efficiency, sustainability and economic growth, Energy 32 (5) (2007) 634–648. [31] J. Asafu-Adjaye, The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries, Energy Econ. 22 (6) (2000) 615–625. [32] S. Paul, R.N. Bhattacharya, Causality between energy consumption and economic growth in India: a note on conflicting results, Energy Econ. 26 (6) (2004) 977–983. [33] U. Soytas, R. Sari, Energy consumption and GDP: causality relationship in G-7 countries and emerging markets, Energy Econ. 25 (1) (2003) 33–37. [34] A. Omri, An international literature survey on energy-economic growth nexus: evidence from country-specific studies, Renew. Sustain. Energy Rev. 38 (2014) 951–959. [35] M.A. Hall, R.F. Wright, Systematic content analysis of judicial opinions, Calif. Law Rev. 96 (1) (2008) 63–122. [36] H.-F. Hsieh, S.E. Shannon, Three approaches to qualitative content analysis, Qual. Health Res. 15 (9) (2005) 1277–1288. [37] S. Elo, H. Kyngäs, The qualitative content analysis process, J. Adv. Nurs. 62 (1) (2008) 107–115. [38] UN-HABITAT, The Habitat Agenda Goals and Principles, Commitments and the Global Plan of Action, Available at: (2003) Accessed 5 November 2017 http:// www.un.org/en/events/pastevents/pdfs/habitat_agenda.pdf. [39] P.W. Gerbens-Leenes, Biofuel scenarios in a water perspective: the global blue and green water footprint of road transport in 2030, Glob. Environ. Chang. Part A 22 (3) (2012) 764–775. [40] M.C. Rulli, The water-land-food nexus of first-generation biofuels, Sci. Rep. 6 (22521) (2016) 1–10. [41] J. Hill, E. Nelson, D. Tilman, S. Polasky, D. Tiffany, Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels, Proc. Natl. Acad. Sci. 103 (30) (2006) 11206–11210 July 25, 2006. [42] J. Olsson, Improved road accessibility and indirect development effects: evidence from rural Philippines, J. Transp. Geogr. 17 (6) (2009) 476–483. [43] A. Tukker, et al., Fostering change to sustainable consumption and production: an evidence based view, J. Clean. Prod. 16 (no. 11) (2008) 1218–1225. [44] E.G. Hertwich, Consumption and the rebound effect: an industrial ecology per- spective, J. Ind. Ecol. 9 (1-2) (2005) 85–98. [45] L.A. Greening, D.L. Greene, C. Difiglio, Energy efficiency and consumption—the rebound effect—a survey, Energy Policy 28 (no. 6) (2000) 389–401. [46] S. Sorrell, J. Dimitropoulos, M. Sommerville, Empirical estimates of the direct re- bound effect: a review, Energy Policy 37 (4) (2009) 1356–1371. [47] USDA, Nutrient Lists, Available at: (2017) Accessed 26 October 2017 https://ndb. nal.usda.gov/ndb/nutrients/report?nutrient1=208&nutrient2=&nutrient3=&

fg=11&max=25&subset=0&offset=725&sort=f&totCount=788&measureby=g. [48] V. Smil, Energy in Nature and Society: General Energetics of Complex Systems (no. Book, Whole), The MIT Press, Cambridge, Mass, 2008. [49] World Bank, Agricultural Land (sq. km), Available at: (2018) Accessed 13 May 2018 https://data.worldbank.org/indicator/AG.LND.AGRI.K2. [50] FAO, The State of Food and Agriculture: Innovation in Family Farming, Available at: Food and Agriculture Organization of the United States, Rome, 2014http:// www.fao.org/3/a-i4040e.pdf. [51] P. Pellegrini, R.J. Fernández, Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution, Proc. Natl. Acad. Sci. 115 (10) (2018) 2335–2340. [52] F. Alluvione, B. Moretti, D. Sacco, C. Grignani, EUE (energy use efficiency) of cropping systems for a sustainable agriculture, Energy 36 (7) (2011) 4468–4481. [53] World Bank, Population, Total, Available at: (2018) Accessed 9 June 2018 https:// data.worldbank.org/indicator/SP.POP.TOTL. [54] USAID, Powering Health, Available at: Electrification Options for Rural Health Centers, Washington, DC, 2011http://www.poweringhealth.org/Pubs/PNADJ557. pdf. [55] African Solar Designs and UN Foundation, "Health Facility Energy Needs Assessment: Ghana Country Summary Report, United Nations Foundation, 2015 Available at: http://energyaccess.org/wp-content/uploads/2016/01/UNF-Health- Clinic-Electrification-Ghana-Country-Summary-Report.pdf. [56] A. Anhar, C.S. Ismail, Studi Komparatif Pemanfaatan Pelayanan Kesehatan pada Masyarakat Pedesaan di Wilayah Kerja Puskesmas Poleang Barat dengan Masyarakat Perkotaan di Wilayah Kerja Puskesmas Lepo-lepo Tahun 2015, Jurnal Ilmiah Mahasiswa Kesehatan Masyarakat 1 (2) (2016). [57] J.C. Wang, A study on the energy performance of school buildings in Taiwan, Energy Build. 133 (2016) 810–822. [58] U.Y. Abeysundara, S. Babel, S. Gheewala, A matrix in life cycle perspective for selecting sustainable materials for buildings in Sri Lanka, Build. Environ. 44 (5) (2009) 997–1004. [59] L.D. Pereira, D. Raimondo, S.P. Corgnati, M.G. Da Silva, Energy consumption in schools–a review paper, Renew. Sustain. Energy Rev. 40 (2014) 911–922. [60] M.H. Chung, E.K. Rhee, Potential opportunities for energy conservation in existing buildings on university campus: a field survey in Korea, Energy Build. 78 (2014) 176–182. [61] M. Khoshbakht, Energy use characteristics and benchmarking for higher education buildings, Energy Build. 164 (2018) 61–76. [62] A. Carroll, G. Heiser, An analysis of power consumption in a smartphone, USENIX Annual Technical Conference 14 (2010) 21. [63] K. Smith, et al., Impact of urban water supply on energy use in China: a provincial and national comparison, Mitig. Adapt. Strateg. Glob. Chang. 21 (8) (2016) 1213–1233. [64] L.A. Miller, A. Ramaswami, R. Ranjan, Contribution of water and wastewater in- frastructures to urban energy metabolism and greenhouse gas emissions in cities in India, J. Environ. Eng. 139 (5) (2012) 738–745. [65] K. Smith, S. Liu, Y. Liu, S. Guo, 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. 91 (2018) 41–58. [66] World Bank, Beyond Connections: Energy Access Redefined, Available at: The World Bank, Washington DC, 2015https://openknowledge.worldbank.org/ bitstream/handle/10986/24368/Beyond0connect0d000technical0report.pdf?sequence=1&isAllowed=y. [67] V. Modi, S. McDade, D. Lallement, J. Saghir, Energy Services for the Millennium Development Goals, Energy Sector Management Assistance Programme, United Nations Development Programme, UN Millennium Project, and World Bank, New York, 2005. [68] World Bank, World Development Indicators 2017: Sustainable Development Goals, Available at: (2017) Accessed 14 May 2018 http://datatopics.worldbank.org/sdgs/. [69] World Bank, GDP Per Capita, PPP (constant 2011 International $), Available at: (2018) Accessed 13 September 2018 https://data.worldbank.org/indicator/NY. GDP.PCAP.PP.KD. [70] IEA, Key World Energy Statistics 2017, The International Energy Agency, Paris, 2017. [71] T. ICT, Measuring Rural Access: Using New Technologies, Available at: The World Bank, Washington DC, 2016http://documents.worldbank.org/curated/en/ 367391472117815229/pdf/107996-REVISED-PUBLIC-MeasuringRuralAccessweb. pdf. [72] UNDESA, Tier Classification for Global SDG Indicators, Available at: The United Nations Department of Economic and Social Affairs, New York, 2018https:// unstats.un.org/sdgs/files/Tier Classification of SDG Indicators_11% 20May 2018_web.pdf. [73] European Commission Energy, Energy Conservation in Road Pavement Design, Maintenance and Utilisation, Available at: European Commission Energy, 2010, https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/ documents/ecrpd_publishable_report_en.pdf. [74] H. Stripple, Life Cycle Assessment of Road: A Pilot Study for Inventory Analysis (Second Revised Edition), Swedish Environmental Research Institute, Gothenburg, Sweden, 2001. [75] Deutsche Bahn, Facts and Figures 2017, Available at: (2018) Accessed 15 May 2018 https://www.deutschebahn.com/en/group/ataglance/facts_figures-1776344. [76] W. Vereecken, et al., Power consumption in telecommunication networks: overview and reduction strategies, IEEE Commun. Mag. 49 (no. 6) (2011) 62–69. [77] A. Mastrucci, N.D. Rao, Decent housing in the developing world: reducing life-cycle energy requirements, Energy Build. 152 (2017) 629–642. [78] N.D. Rao, P. Baer, “Decent living” emissions: a conceptual framework, Sustainability 4 (4) (2012) 656–681. [79] K. Wiebe, Measuring Winnipeggers’ Convenient Access to Public Transit, Available at: The International Institute for Sustainable Development, Manitoba, 2018https:// www.iisd.org/sites/default/files/publications/measuring-winnipeg-access-public- transit.pdf. [80] P. Newman, J. Kenworthy, Evaluating the transport sector’s contribution to greenhouse gas emissions and energy consumption, in: R. Salter, S. Dhar, P. Newman (Eds.), Technologies for Climate Change Mitigation-Transport Sector, UNEP Riso Centre on Energy, Climate and Sustainable, Roskilde, 2011, pp. 7–23. [81] P. Beigl, S. Salhofer, Comparison of ecological effects and costs of communal waste management systems, Resour. Conserv. Recycl. 41 (2) (2004) 83–102. [82] FAO, Issue paper, Energy-Smart Food for People and Climate, Food and Agriculture Organization, Rome, 2011 Available at: http://www.fao.org/docrep/014/i2454e/ i2454e00.pdf. [83] J. Gustavsson, C. Cederberg, U. Sonesson, R. van Otterdijk, A. Meybeck, Global Food Losses and Food Waste: Extent, Causes and Prevention, FAO, Rome, 2011 ed. [84] J. Cleary, Life cycle assessments of municipal solid waste management systems: a comparative analysis of selected peer-reviewed literature, Environ. Int. 35 (8) (2009) 1256–1266. [85] A. Atmaca, N. Atmaca, Comparative life cycle energy and cost analysis of post- disaster temporary housings, Appl. Energy 171 (2016) 429–443. [86] K. Hinton, J. Baliga, M. Feng, R. Ayre, R.S. Tucker, Power consumption and energy efficiency in the internet, IEEE Netw. 25 (no. 2) (2011). [87] B. Vilhelmson, E. Thulin, E. Elldér, Where does time spent on the Internet come from? Tracing the influence of information and communications technology use on daily activities, Inf. Commun. Soc. 20 (2) (2017) 250–263. [88] A. Menezes, A. Cripps, R.A. Buswell, J. Wright, D. Bouchlaghem, Estimating the energy consumption and power demand of small power equipment in office buildings, Energy Build. 75 (2014) 199–209. [89] W.G. Santika, T. Urmee, M. Anissuzaman, G. Shafiullah, 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 (2018). [90] D. Pimentel, Energy inputs in food crop production in developing and developed nations, Energies 2 (1) (2009) 1–24. [91] UNDESA, Indicator : 2.1.1 - Prevalence of Undernourishment, Available at: (2017) Accessed 26 October 2017 https://unstats.un.org/sdgs/indicators/database/?indicator=2.1.1. [92] GOI, The Analysis of the Food Consumption Dinamics of Indonesians, The Ministry of Trade of Indonesia, Jakarta, 2013. [93] GOI, 2011-2015 Roadmap of Food Diversification, The Food Resilience Agency of The Ministry of Agriculture of Indonesia, Jakarta, 2012. [94] World Bank, Energy Use (kg of Oil Equivalent Per Capita), Available at: (2018) Accessed 7 October 2018 https://data.worldbank.org/indicator/EG.USE.PCAP.KG. OE?locations=XO-XD&name_desc=false.

W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 W.G. Santika et al. Energy Research & Social Science 50 (2019) 201–214 202 203 204 205 206 207 208 211 212 213 214